Bog at Everett Lake in Geauga County, showing the absence of aquatic plants—a feature peculiar to northern bogs—and the abrupt transition from the swamp loose-strife border (*Decodon verticillatus* association) through a narrow belt of cranberry-sphagnum meadow and scattered bog heaths to tamarack. The outer margin of the bog has maple, ash, elm and others.

(*Photograph by L. King.*)

GEOLOGICAL SURVEY OF OHIO

J. A. BOWNOCKER, State Geologist

FOURTH SERIES, BULLETIN 16

IN COÖPERATION WITH THE UNITED STATES BUREAU OF MINES

PEAT DEPOSITS OF OHIO

THEIR ORIGIN, FORMATION AND USES

By ALFRED DACHNOWSKI

COLUMBUS, OHIO
1912

Published by authority of the Legislature of Ohio, under
the supervision of the State Geologist

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GOVERNOR JUDSON HARMON:

Dear Sir:—I transmit herewith Bulletin 16 of the Geological Survey, entitled "Peat Deposits of Ohio," by Dr. Alfred Dachnowski. The disappearance of our forests and the predicted early depletion of our coal supply naturally causes grave concern for the future. What our fuel will be no one can state, but peat is now used on a large scale in various parts of Europe and it will doubtless have its day in the United States. The use of this material, however, is not restricted to fuel and it has seemed wise, therefore, to take an inventory of these deposits in Ohio and the results are recorded in this bulletin. Dr. Dachnowski has pursued the investigation with notable energy and enthusiasm and his results will doubtless be welcomed by our citizens as well as by geologists and botanists.

Respectfully submitted,
J. A. BOWNOCKER,
State Geologist.

April 1, 1912.

THE SURVEY IN ITS RELATIONS TO THE PUBLIC.

The usefulness of the Survey is not limited to the preparation of formal reports on important topics. There is a constant and insistent desire on the part of the people to use it as a technical bureau for free advice in all matters affecting the geology or mineral industries of the State. A very considerable correspondence comes in, increasing rather than decreasing in amount, asking specific and particular questions on points on local geology.

The volume of this correspondence has made it necessary to adopt a uniform method of dealing with these requests. Not all of them can be granted, but some can and should be answered. There is a certain element of justice in the people demanding such information, from the fact that the geological reports issued in former years were not so distributed as to make them accessible to the average man or community today. The cases commonly covered by correspondence may be classified as follows:

1st. Requests for information covered by previous publications.—This is furnished where the time required for copying the answer is not too large. Where the portion desired cannot be copied, the enquirer is told in what volume and page it occurs and advised how to proceed to get access to a copy of the report.

2nd. Requests for identification of minerals and fossils.—This is done, where possible. As a rule, the minerals and fossils are simple and familiar forms, which can be identified at once. In occasional cases, a critical knowledge is required and time for investigation is necessary. Each assistant is expected to coöperate with the State Geologist in answering inquiries concerning his field.

3rd. Requests from private individuals for analyses of minerals and ores, and tests to establish their commercial value.—Such requests are frequent. They cannot be granted, however, except in rare instances. Such work should be sent to a commercial chemical laboratory. The position has been taken that the Geological Survey is in no sense a chemical laboratory and testing station, to which the people may turn for free analytical work. Whatever work of this sort is done, is done on the initiative of the Survey and not at the solicitation of an interested party.

The greatest misapprehension in the public mind regarding the Survey is on this point. Requests for State aid in determining the value of private mineral resources, ranging from an assay worth a dollar, up to drilling a test well costing several thousand dollars, which represent extreme cases, are received. At present there is no warrant for the Survey making private tests, even where the applicant is entirely willing to pay for the service. In many cases individuals would prefer the report of a State chemist or State geologist to that of any private expert, at equal cost, because of the prestige which such a report would carry. But it is a matter of doubt whether it will ever be the function of the Survey to enter into commercial work of this character; it certainly will not be unless explicit legal provisions for it are made.

4th. Requests from a number of persons representing a diversity of interests, who jointly ask the Survey to examine into and publicly report upon some matter of local public concern.—Such cases are not common. It is not always easy to determine whether such propositions are really actuated by public interest or not. Each case must be judged on its merits. The Survey will often be prevented from taking up such investigations by the lack of available funds, while otherwise the work would be attempted.

The reputed discovery of gold is one of the most prolific sources of such calls for State examination. It usually seems wise and proper to spend a small sum in preventing an unfounded rumor from gaining acceptance in the public mind, before it leads to large losses, and unnecessary excitement. The duty of dispelling illusions of this sort cannot be considered an agreeable part of the work of the Survey, but it is nevertheless of very direct benefit to the people of the State.

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Under the law, copies of these Bulletins can be bought at the office of the State Geologist at the cost of publication. Postal orders, money orders, checks, drafts or currency must accompany orders. STAMPS WILL NOT BE ACCEPTED.

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FOURTH SERIES BULLETIN 16

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By ALFRED DACHNOWSKI

APRIL, 1912

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INTRODUCTION

Among the fundamental problems in Geology is that which relates to the origin as well as to the nature of soils. But the origin of soils, though a geological question, can often be approached only by the methods which the botanist employs, while the consideration of its nature, its productivity, and rational treatment, problems which touch the very foundation of a state's prosperity, are very largely within the domain of botany and that of its more practical aspect, agriculture. Thus we see that certain phases of geological inquiry have as definite and vital a concern for the commercial and agricultural interests as other lines of geological investigation have for the limestone and coal and iron industries of the State.

It is a matter of common knowledge that the whole progress of the human race has been due to the discovery of means of conserving and concentrating energy, and of transforming one form into another with as little expenditure as possible. There is only a limited supply of stored-up energy in this world which may readily be transformed into various other available forms, and the consumption of such available supplies is proceeding at a rapid and ever accelerated rate. The time will soon arrive when the several sources of energy and their economic employment will have to be considered with greater thoughtfulness. With the exception of the energy obtainable from water power, forests, and our great carbon deposits in the form of coal and peat, none of the other sources, such as wind, solar heat and tides, can as yet be considered seriously as possible supplies for energy. Attention must, therefore, be paid chiefly to our forest policy and to the utilization of our peat deposits.

In 1909 the writer was directed to obtain for the Geological Survey of Ohio an estimate of the extent and value of the peat-bog and marshland in Ohio, to determine the depth of these deposits, their general physical and chemical characters and in particular to study them with a view to their fuel, commercial and agricultural utilization.

There has recently been shown a renewed interest in the problems of peat utilization. In Europe this question is receiving the most careful and exhaustive study by trained specialists. Reports from that country indicate the success of various new processes such as Ekenberg's for briquetting peat, the Ziegler method for the production of coke, the process of Caro, Frank and others for the distillation of peat, permitting the recovery of valuable by-products, alcohol, and gas; the Waltereck patent and that of Müntz and Girard converting peat nitrogen into ammonia and nitrates; Nelson's process for making paper. It is, therefore, a matter of the greatest importance to determine the extent of our own peat resources, the conservation of which should be second to none of the other economic sources of wealth. The uses of peat are many. It can be employed as packing material, bedding, absorbent, fertilizer filler, as insulating material, for paper pulp and cardboard, in woven fabrics, artificial wood, paving and building blocks and for mattresses. The chemical by-products derived from the distillation of peat, such as alcohol, ammonium sulphate, nitrates, and various dyes, have a demand which is steadily increasing. There is an interesting chapter on peat utilization as fuel, power or producer gas, and coke. Many of our peat lands make our most productive agricultural soils when properly reclaimed.

Very interesting studies are connected with the agricultural possibilities of peat soils: the physiological value of organic compounds in peat to cereals and legumes; the character and variety of crops and garden plants which may be profitably cultivated on peat land; the sterility and the diseases of some of these soils; the nature of functional and structural responses in plants to such soils, and many other problems. This is a period of "intensive" agriculture, of investigation and discovery, and attention must sooner or later be turned towards our immense peat deposits.

The plants concerned in the formation and development of bogs and marsh lands bear a relation of the utmost importance to the purity, character, and thermal and physiological value of peat soils. The bearing of a floristic study upon the distribution of bog and marsh plants is also of considerable ecological and agricultural interest. The aim has been, therefore, not only to present a list of the plants found in the various areas visited, but to show also the natural association of the plants into societies, the order in which development and succession of plants in bogs proceeds, and the value which the natural vegetation has as an index of the probable agricultural possibilities of peat soils. Moreover, the present bog and marsh plant societies are being destroyed so rapidly that some historical record is indeed of primary importance. In almost all places the work of man has inaugurated conditions by cutting, clearing, burning, ditching, pasturing, and cultivating, which have destroyed much of the original flora of Ohio; and hence in many places a mixture of arborescent plants, bog relicts, weeds, and invading plants has established itself. But even under such conditions an order of invasion and succession is to a certain extent characteristic in the movement of plants, and depends largely upon the extent to which the plants are enabled to cope functionally and structurally with the changing conditions and hold their ground.

The following bulletin on the peat deposits of Ohio has been prepared by the Geological Survey of Ohio in co-operation with the United States Bureau of Mines. The bulletin contains the proximate analyses of peat samples and their fuel value. With but one exception all of these analyses have been made in the fuel testing laboratory of the United States Bureau of Mines at Pittsburgh, under the direction of Mr. A. C. Fieldner.

The writer is under special obligations to Dr. J. A. Bownocker, State Geologist, for the opportunity to investigate this most interesting problem of economic and historical geology, for much valuable aid and for his contribution on the soils and the topography of the State (pp. 199–203). Dr. Charles A. Davis, in charge of the peat investigations of the United States Bureau of Mines has been particularly helpful in furthering the coöperative work of the peat investigation. Chapter V on the utilization of peat has been contributed by Dr. Charles A. Davis. Prof. J. H. Schaffner and Dr. F. Detmers have unsparingly aided in the identification of plants. In consideration of recent differences in nomenclatorial practice synonyms have been inserted freely, to show the equivalence of different names which occur in Gray's Manual and that of Britton. To avoid repetition the botanical names have not been inserted in all cases with the common names. These names are indicated in the Index. The maps showing peat deposits and several figures in the text are due to the skill of Mr. W. D. Turnbull. Most of the photographs have been prepared by Mr. Lionel King and Mr. F. Brown. Much coöperation has been received in the bacteriological examinations from Prof. C. B. Morrey, and in the chemical analyses from the late Professor N. W. Lord, Professors W. E. Henderson, C. W. Foulk of the Ohio State University, and J. W. Ames of the Ohio Agricultural Experiment Station. It is a great pleasure to express the appreciation which the writer feels for this coöperation. It is a distinct advantage to use the exact information which by the courtesy of colleagues and specialists is given in this contribution.

A number of gentlemen, owners of the peat deposits, county officials and citizens of the respective counties visited, have given most valuable information and generous personal assistance at such times as it has been the writer's privilege to consult them. It is a pleasure to acknowledge indebtedness to them all.

Much information has been obtained also from a large number of publications, especially the many earlier histories of the respective counties and townships of the State. In the preparation of this bulletin the writer has used freely the experimental laboratory work and the special ecological investigations carried on by himself and students for the past eight years. Several of the later papers have been published by permission of the State Geologist. Much of the earlier subject-matter has been published at one time or another in the Botanical Gazette and special acknowledgment is due, therefore, to Professor Coulter of the University of Chicago for permission to use the illustrations and the various publications which appeared in that periodical. To make the various lines of investigation more easily accessible, the material has been recast in its present form.

PART I

Peat, Its Distribution and Uses

CHAPTER I

GENERAL DISCUSSION

Interest in peat as fuel, as soil and as partially carbonized vegetation dates back to early history. Scarcely less ancient are the attempts to use it for domestic and other purposes in those regions where peat and marsh land have been the only natural resources over wide areas.

Exact and systematic study of peat began in Europe in 1750 when various scientific societies offered prizes for memoirs on the origin, formation and nature of peat. Then as today some persons held that peat bogs were useless obstacles to commerce and agriculture; were places of malarious fevers and the causes of spring frosts; while others advanced the idea that peat, if once dug out, would grow again spontaneously. Since 1829 and especially beginning with 1844, the peat problem has been studied carefully and persistently. To Leo Lesquereux, a Swiss botanist with enthusiastic devotion to natural history studies, who died in Columbus, October 20, 1899, belongs the honor of having been the pioneer in the application of scientific methods. By means of quantitative measurements he attempted to discover and to correlate the fundamental facts of this great problem. The most comprehensive modern monograph is undoubtedly the volume of Früh and Schröter, issued by the Swiss Geological Commission in 1904. Numerous other publications and various periodicals are exclusively devoted to peat and its uses; they are issued in almost every European country and in the United States and Canada. But the number of unquestioned facts and experiments is still scanty, and further work will be necessary to set clear and answer the many complicated questions.

Definition.—To give an explanation of the word "peat" would lead one far into the science of language. It is of Celtic or Welsh origin and probably has been modified by mediaeval Latin. A definition of the thing itself will naturally differ according to the point of view. With reference to its economic importance peat is a fuel and is usually regarded as an initial stage in the formation of coal; as a portion of the earth's surface upon which plants grow, peat is a soil; with reference to its constitution, appearance and relation to other objects that serve to distinguish it from other things, peat is partly decomposed plant tissue.

It is difficult to draw sharp lines of distinction if a classification of the different types of peat is attempted. Based upon purely physical characters three varieties may be pointed out. But disintegrating vegetable matter is exceedingly variable even in the same bog. The variability is unimportant for fuel purposes; for certain other uses, however, as in the industries and in agriculture much depends upon the physical condition of the peat. Texture, structure, composition, water-holding capacity and such differences as may be indicated by weight, density and specific gravity often bear an important relation to the chosen field of exploitation.

Varieties of Peat.—In any undrained or partly drained water basin of Ohio where peat is accumulating, two varieties of the material may be readily distinguished. One is coarsely fibrous and matted, containing the roots, rhizomes and aërial parts of plants from which the organic matter is derived. It has a light brown color, definite physical and chemical properties and often lies as a floating mat near open water on account of its low specific gravity. The outer covering of the plant material is more or less strongly cuticularized, disintegrates very slowly and hence is still in the early stages of partial decay. The other variety is a dark brown, almost black, well decomposed, compact peat which is usually found near the outer margin of the deposit and above the ground-water level. The fibrous structure is less apparent for it has disappeared through decay, and the larger part of the annual peat increment is made up of leaves and disintegrating woody parts of trees and shrubs. Between these two varieties peat samples collected from a horizontal or vertical cross section are found in various intermediate stages of disintegration. This is indicated in most deposits by a progressive change in color from light to darker shades and in texture from coarse, loose and matted to fine, plastic and often more liquid peat which results largely by the gradual falling of material from the under side of the floating and strongly matted variety. The chemical composition, the biological soil processes, and the physiological properties of the different varieties and types of peat also vary, as will be shown in the following chapters.

In shallow basins and upon flat areas a third but, in Ohio, a less common variety of peat is formed. Grasses and sedges chiefly build up the deposit from the bottom of the depression with the successive elevation of the water level. Peat of this type is felt-like and firm in appearance; but the fibers are short and the material is easily torn apart.

Quality.—The quality of peat depends upon a number of conditions. The more important of these are (1) the amount of impurities, (2) the nature of the vegetation from which the peat originated and (3) the degree of disintegration.

1. The mineral matter represents largely the sediment carried into the peat deposits by streams or the dust brought to it during dry and windy periods (pp. 377–380). The quantity of mineral salts accumu-

lated during the life processes of plants is very small, rarely 2 per cent of their dry weight. In the limestone region of Ohio a large per cent. of peat ash consists of calcium salts which have been secreted from the ground water principally by algae. Upon their death the material precipitates in the form of marl. Small animals such as crustaceans and bivalves contribute shells, and a number of organisms concentrate by the same process salts of silica, magnesium and other minerals. The per cent. of impurities usually diminishes as the thickness of the peat bed increases. Peat which contains over 25 per cent. of ash is considered worthless for fuel purposes. Where the proportion is still larger the term *muck* is applied. If the surface layer of a peat deposit is above the ground-water table and exposed to weathering and to soil organisms living in the air, it disintegrates more readily and changes to a darker color; it is then called *humus*. No sharp lines of distinction can be drawn between peat and humus.

2. Peat is accumulated through the successive generations of plants and the replacement of one type of bog vegetation by another (Fig. 13). The rate of growth and accumulation is variable but very slow. The majority of the Ohio deposits are in the Wisconsin drift, and hence the filling has been going on since the retreat of the last ice sheet (Chapter V, p. 217). The average rate of accumulation is assumed to be approximately one foot in about two hundred years. As aggradation proceeds the lower portions are compressed to about one-fourth of their former thickness.

The plants from which peat is derived are commonly associated in more or less definite groups. Each possesses definite growth-form, structures, and mode of functioning, which are in close relation to the conditions of the environment. These characteristics of the plants are in part congenital, and in part a product of the specific nature of the habitat. Various factors enter into the correlation (p. 307), but the relation between the sanitary conditions of the soil and the available water content to the respective quantity of water required by the plants, is the chief limiting factor. These plants alone are successful, and enabled to survive the critical features of the environment through advantageous reactions. Plant associations covering peat deposits have been variously classified, but usually into unrelated groups. The basis of a genetic classification is migration and replacement occurring at the same time with changes in the soil processes. For example, a marsh, the vegetation of which is principally grass-like (reed grasses, cattails, etc.), is an obvious and rapid stage in succession between the aquatic associations of ponds and lakes and the bog, forest or swamp. The last named, as here understood, has trees and shrubby plants as the more important part of the vegetation, upon an undrained soil subject to flooding. These types all intergrade more or less, and often exist in the same basin. In another chapter will be presented some of the striking features and relationships of the more important plant associations.

Both texture and quality of peat naturally depend upon the kinds of plants growing in the basin. Water plants form a structureless soft material. Sedges and grasses furnish the fibrous turf which is generally poorly decomposed, except when it accumulates above the water level. Trees and shrubs give rise to woody peat. Frequent changes in the conditions of growth or attendant upon the disintegration of the material likewise result in differences of composition and texture.

The surface vegetation does not necessarily indicate the plants from which the peat was formed, but the native flora is nearly always of a character indicating the quality of the peat, and the capability of the soil for general farming. The choice of crops should, however, be determined by considerations of the plants fitted for such soils. A knowledge of the plant and an understanding of the various properties of soils of an organic nature are of the greatest importance for success. Peat soils are very different from mineral soils. The chapters on the physiological, chemical and biological properties of peat consider these points more fully.

3. The degree of disintegration is indicated in general by the shade of color, water-holding capacity, density and weight of a given volume of peat. Under natural conditions and when freshly removed from the bog, peat contains usually a large amount of water, ranging from seventy to ninety-five per cent. When air-dried, peat contains from 5 to 20 per cent. of water. The quantity varies partly with the physical character of the peat, and partly with the climate and the season in which it is allowed to air-dry. In general, the more fibrous the peat the higher its physical water content, but its water-holding power is proportionately less (Table 33). Well decayed and dark brown peat retains a large amount of water. Fibrous and light colored peat is light in weight when compared with the darker, more disintegrated material. The dry weight per cubic foot of the former variety ranges, according to German authorities, between 7 and 16 pounds; that of the latter is from 40 to 60 pounds. The weight will be greater if the ash content is higher than 15 per cent. There is, on the whole, a close relationship between the progressive changes in color, texture, water-holding capacity and specific gravity of the different types of peat as the bed is cut through vertically or horizontally. The chemical composition and the several properties vary similarly, as might be expected.

Peat, when macerated and compressed, undergoes physical and chemical changes; it becomes firm and hard, and no longer absorbs water with readiness. Numerous tests, corroborated by various writers, show, (1) that peat from bog mosses has a higher fuel value than the grass and sedge variety and (2)that compared with the more compact and disintegrated material and the peat substratum occupied by bog shrubs and forests, it contains less carbon, more oxygen and hydrogen, and has a lower specific gravity and fuel value.

Primary Conditions.—The primary conditions for the origin, formation and distribution of peat deposits will be pointed out with greater detail in succeeding chapters. Here it is sufficient to indicate that peat is the accumulation of plant debris in a relatively permanent body of water, or in moist shallow places; in the latter case the deposit is built upward from the bottom of the depression. In both places the partial disintegration of plant tissue is brought about partly by weathering processes and partly by bacteria and fungi. The various products of the decay-producing organisms accumulate in the substratum, and the restricted access of air further checks a complete disintegration of the debris. It is thus evident that the distribution of peat deposits in Ohio is chiefly confined to regions in which a combination of topographic factors and soil processes is operative.

The principal topographic conditions favoring the formation of peat are found in regions where processes of stream erosion and of sedimentation are slight or have been at work a comparatively short time; where the topography abounds in depressions, flat divides, sheltered bays, lagoons, bayous, oxbow basins, in depressions between sand dunes and in plains from which the water is but slowly drained; where lakes and ponds are not too deep or too much agitated by waves and sediments and are not drained by the deepening of channels near the heads of rivers and their tributaries. The geographical distribution of peat deposits shows that regions of immature topography, that is, glaciated areas and tracts along the coastal plain of both the northern and southern hemisphere, are particularly favorable to the accumulation of this material.

The role which microörganisms and fungi play in the changes taking place during the transformation of plant tissue into peat, has been ignored or doubted by most workers, while others regard the bacterial influences as very small.[1] In almost no cases were studies carried on to obtain more specific information. It is only very recently that bacteriological investigations have been made to show the importance of biological processes over weathering influences, to indicate the reaction of bacterial by-products upon higher plants, and to determine their possible relation in the displacement of one bog association by another in the same peat deposit.[2] The decay of vegetable matter is a complicated series of changes and must be ascribed partly to the action of air, moisture and temperature, but largely, however, to the

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[1]Früh, J. und Schröter, C., Die Moore der Schweiz. Bern, 1904.

[2]Dachnowski, A., Physiologically arid habitats and drought resistance in plants. Botanical Gazette, vol. XLIX, 1910, pp. 330-335.

——————, The vegetation of Cranberry Island (Ohio), and its relation to the substratum, temperature and evaporation. Botanical Gazette, Vol. LII, 1911, pp. 15-21.

growth and development of low soil organisms (Chapter X). The organisms which aid in the decay are mainly bacteria and fungi; they are relatively simple in structure, mostly of microscopic size, and they lack the green color. The largest forms may reach a diameter of 0.000352 inch (0.008 mm.), and the majority are not more than 0.000197 inch (0.005 mm.) in diameter. Some bacteria are too small to be seen even with the most powerful microscope. Bacteria are concerned with almost every important phase of soil in relation to life.[1] They are most numerous near the surface and decrease more or less rapidly in numbers downward. The majority of them thrive even when air is excluded. Many types of animals, very low in the scale of organization, aid in bringing about decomposition.

The functions and value of peat bacteria are variable. When the conditions of air, temperature, moisture and character of food supply are favorable, decay-organisms may bring about a rapid and complete disintegration of plant tissues into simple gaseous compounds such as carbon dioxide and water, from which green plants build up the world's supply of organic matter. Under favorable conditions the conversion of plant tissue into peat and humus may be accompanied by fungoid and bacterial growth which affects an increase in the nitrogen content of the debris, possibly by the property of utilizing atmospheric nitrogen and transforming it into the organic state. Some of the organisms live in symbiotic association with plants other than the legumes (*Alnus*), and may be a factor in determining the natural succession of bog vegetation not explained by any change of climate or physical soil conditions.

The process of decay goes on very slowly and is then less complete if the conditions are unfavorable, that is, if the character of the organisms and the nature of the organic compounds produced result in the accumulation of an excess of their own by-products, and the organic matter is not suitable for other forms or suitable only for bacteria, fungi, and protozoa producing harmful products. During the slow and partial decomposition the softer plant tissues are more easily broken down into simpler compounds. They disappear as carbon dioxide and marsh gas, or accumulate as "humus acid" (p. 386), and as complex organic "reducing" compounds soluble in water—none of which can be said to be chemically well known. Some of the organic compounds are transition products and injurious to higher plants (Figs. 16–21), while others have a nutritive value (Table 22). The secondary products are very numerous, and are readily affected by the temperature in the soil and the amount of air and water which it contains. They are of widely varying composition, structure, physical and chemical properties, and very different under different conditions. The resistant woody plant tissues remain more or less unchanged, but later, as they become buried under suc-

[1]Kellerman, K. F., The functions and value of soil bacteria, Yearbook, U. S. Dept. Agri., 1909, pp. 219-226.

cessive layers and protected from atmospheric oxidation, they are at the same time subjected to fermentation, to a reduction process, and to a gradually increasing pressure. By a series of changes which are plainly traceable though not fully understood, the plant tissues thus become carbonized to peat, lignite and coal.

Secondary Conditions.—In this connection the geographical distribution of peat deposits is of interest. There are a number of localities where climatic conditions are the principal factor favoring the formation of this material. Even when the topography is not favorable and lakes or ponds do not exist, an abundant rainfall or heavy fogs during the warmer months make the formation of peat possible (p. 285). Again, there are extensive areas within regions of the most favorable topography, where the climate is too dry and the depressions, though filled with water part of the time, either dry up at some season of the year, fluctuate in level too greatly, or contain too much sediment or mineral salts. In such depressions the vegetable matter which may grow and accumulate during the wet season, oxidizes when dry; it loses its gaseous constituents and becomes structureless, darkening in color as the weathering process acts upon it. With continued free access of air the accumulation of vegetation soon undergoes complete disintegration and finally disappears. Some of the western states are examples of unfavorable climatic conditions.

It goes without saying that the formation of peat is favored in areas where the temperature during the growing season is sufficiently mild to permit plants to thrive in abundance (Chapter VIII). The formation of peat in regions as far south as Florida,[1] in Brazil[2] and even about the equator[3] is indicative that high temperature does not prevent the formation of peat, nor does it promote in a marked degree decomposition of the material unless the humidity of the air or the topography is unfavorable to the growth of green plants, fungi and bacteria, and to the consequent accumulation of injurious decomposition products. Nor does a low soil or air temperature, if within the limits of organic functioning and growth, tend in any way to increase or to hinder the process of peat formation or the preservation of the debris (pp. 292–306). It should not be inferred, however, that such temperatures are ineffective. The efficiency of low temperature and especially of smaller differences in range is one of interrelations, as is the case of most environmental factors.

[1]Harper, M. R., A Preliminary Report on the Florida Peat Deposits, Florida Geological Survey, 1910, p. 197.
[2]Usteri, A., Flora der Umgebung der Stadt Sao Paulo in Brasilien, Jena, 1911.
[3]Potonié, H., Die Entstehung der Steinkohle, 1910, p. 152.

CHAPTER II

OCCURRENCE AND GENERAL DISTRIBUTION OF PEAT

General Distribution.—Peat occurs in many localities in widespread and extensive deposits. It is found in great abundance in Europe and Asia, in the southern part of Africa, in the United States and Canada, in South America,[1] in Brazil,[2] in Terra del Fuego, the Falkland Islands,[3] and even along the equator.[4]

Europe is said to contain 212,700 square miles of bog, Canada 30,000,000 acres, and the United States 20,000,000 acres. Peat bogs are common in Norway, Sweden and Ireland, on the North German plain and in large parts of Scotland and Holland. There are extensive deposits, about 70,000 square miles, in European and in Asiatic Russia. In northern Europe alone it is estimated that approximately 10,000,000 tons of peat are prepared and consumed annually as fuel, stable litter, for sanitary purposes, and in various trades and arts. Russia produces 4,000,000 tons annually, Germany 2,000,000, Holland and Sweden each 1,000,000. A marked development in the utilization of peat for the manufacture of fuel, illuminating and producer gas, for the production of ammonium salts and other by-products, has recently taken place in Sweden, Germany, Russia and in other countries of Europe, and has aroused new interest in the possibility of the full latent value of peat deposits as public resources.

Distribution in the United States.—The area of the peat deposits in the United States and the quantity workable are almost unknown, but the glaciated areas constitute the greater bulk of the deposits. The southern boundary is very nearly marked by the line of the terminal moraine. Along and beyond the southern border the peat deposits are scattered and make but a small fraction of the total land surface. Northward as the tundra region is reached,[5] the proportion of peat deposits relative to the total land surface increases, and the accumulation of peat is almost continuous over wide areas and in situations other than those containing water. The partially decomposed vegetation becomes solidly frozen and increases from year to year by additions to its surface during the few but long summer days.

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[1]Darwin, Charles, Naturalist's Voyage Around the World, 1868, pp. 287-288.
[2]Usteri, A., Flora der Umgebung der Stadt Sao Paulo in Brasilien, Jena, 1911.
[3]Jour. Geology, Vol. 16, 1908, p. 585.
[4]Potonié, H., Die Entstehung der Steinkohle, 1910, p. 157.
[5]Russell, I. C., Glaciers of North America, 1901, p. 129.

In the mountains of eastern and western United States, Harshberger[1] reports bog meadows and marshes in association with mountain lakes as well as in situations irrespective of the nature of the depression. The conditions are quite similar to those of northern latitudes.

The peat deposits of the coastal plain are not nearly so extensive as those in the north and yet the accumulation is none the less on a large scale. Peat formation reaches its greatest development in Florida, on the Mississippi flood plain, in North Carolina, and Virginia. The vegetation from which it is derived is noted for its luxuriance and density and has been described by Harper, Kearney, Shaler and others.

On the basis of various sources of information (such as publications and topographic maps of the United States Geological Survey, reports of the state geological surveys of New York, Michigan, Iowa, Indiana, Massachusetts and New Jersey; the coöperative work and peat surveys undertaken by the states of Connecticut, Maine and Wisconsin, and his own personal observation), Davis[2] estimates that the total area of swamp land in the United States is nearly 140,000 square miles. Of this eight per cent. or about 11,200 square miles, is assumed to have peat beds of good quality, averaging at least nine feet in depth, and containing 200 tons of dry fuel per acre for each foot in thickness. This equals 12,888,500,000 tons of dry fuel. Its value at $3.00 per ton, if compressed into peat bricks, would be $38,665,700,000. The value of the coke and by-products Davis summarizes as follows:

TABLE I

ESTIMATED QUANTITY AND VALUE OF PEAT COKE AND BY-PRODUCTS FOR THE UNITED STATES FOR THE YEAR 1908.

	Product in Tons.	Value.
Peat coke	3,608,800,000	$26,005,300,000[3]
Illuminating oils	257,800,000	4,474,200,000
Lubricating oils	90,200,000	
Paraffine wax	38,700,000	3,479,900,000
Phenol	167,500,000	66,345,100,000
Asphalt	25,800,000	824,900,000
Wood alcohol	43,800,000	7,844,000,000
Acetic acid	56,700,000	2,268,800,000
Ammonium sulphate	39,900,000	2,777,400,000
Combustible gases	738,400,000	6,501,300,000

It is clearly apparent that in the peat deposits of the United States there lies a vast amount of raw material which for the greater part has been left undeveloped The states containing peat that might be

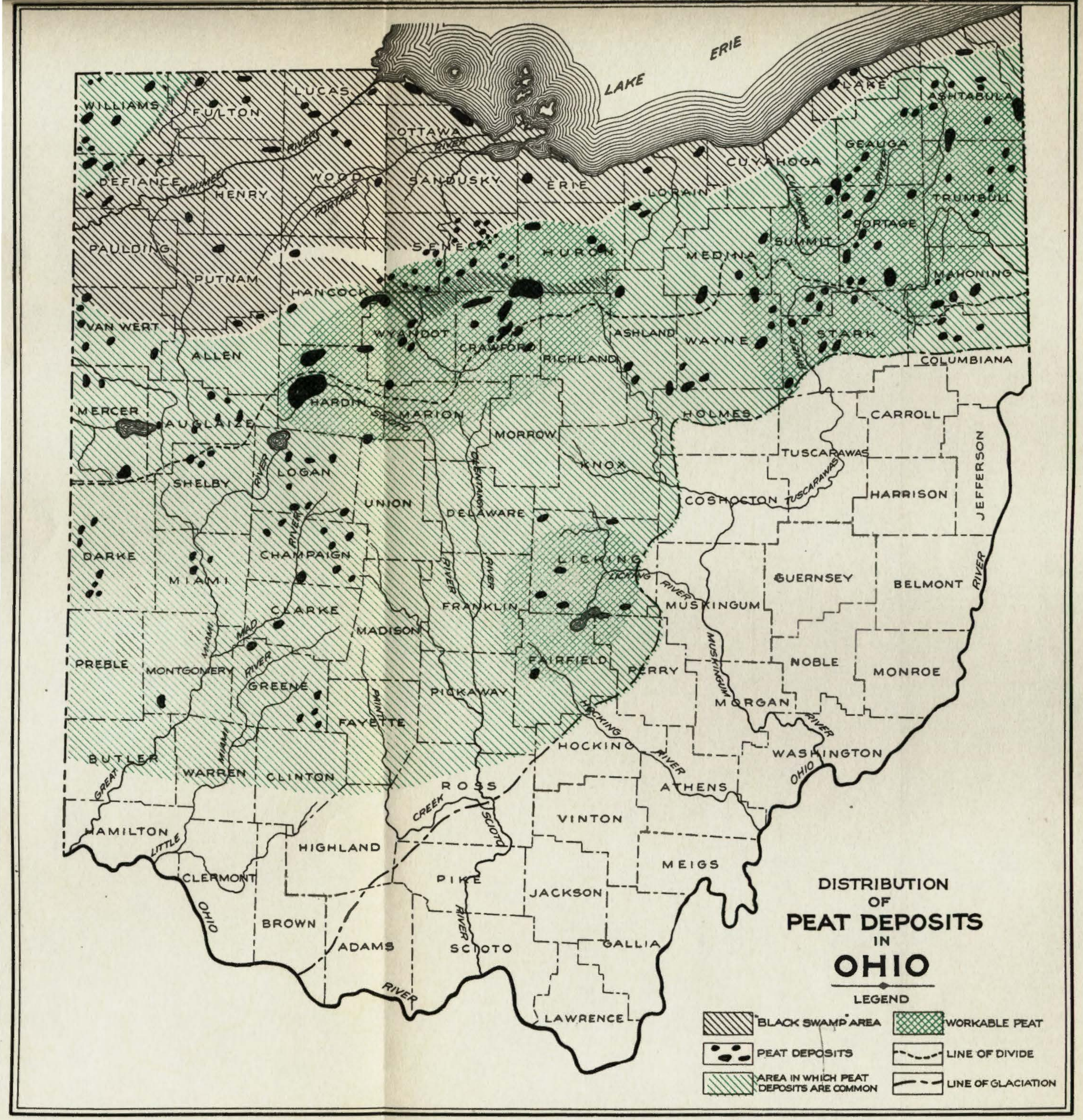
[1]Harshberger, J. W., Die Vegetation der Erde, Vol. XIII, 1911.
[2]Davis, C. A., Peat Resources of the United States, exclusive of Alaska. Bull. U. S. Geol. Survey, N. 394, 1909, pp. 62-69.
[3]Charcoal price. At coke price the value would be $9,924,200,000.

utilized economically and which would serve to supplement the resources of the nation are Ohio, Indiana, Illinois, Michigan, northern Iowa, Wisconsin, Minnesota, the eastern Dakotas, the New England states, New Jersey, New York, the coastal portions of Virginia, North and South Carolina, Georgia, the swampy parts of the Gulf and the Pacific states, and practically all of Florida. The most extensive utilization has been in Canada, but factories are already in operation in the New England states, in New Jersey, New York, Michigan, Illinois, Wisconsin, Florida and Ohio.

Few statistics are available on the production of peat in the United States. In 1908 the value of the products is quoted at $133,000, for 1909 at $127,042, and for 1910, at $140,209. In 1909 23,000 tons of peat were manufactured with an average value of $5.25 per ton, and 8,000 bales each of 225 pounds of moss litter, valued at $1.25 per bale. The imports of peat moss were as follows:

1906	7,343 tons	$43,882
1907	7,602 tons	44,660
1908	8,130 tons	47,829
1909	8,371 tons	46,222
1910	7,872 tons	43,082

Distribution of Peat Deposits in Ohio.—The topography of the central and northern part of the State (Fig. 12) is still relatively immature, especially along the divide or watershed which separates the waters of the Ohio River from those of Lake Erie. The physical features near the lake are quite free from any marked elevations or depressions, and the irregular lake shore favors the development of marshes. The lower courses of the streams are usually sluggish enough to become well clogged with vegetation. But in general such accumulations of plant debris are shallow and not of commercial significance. The interior of the State, which is undulating, has a somewhat different geological history from the marginal plains. In the areas of glacial deposition the topography has innumerable irregular depressions, deposits of gravel, sand and clay, and series of ridges and hollows which seem distributed over the State without order. They are a part of a belt of similar physiography extending from Indiana to Pennsylvania and up into Michigan (see map, p. 27). The southern portion of the State is a region of steep hills. The time which has elapsed since these changes ensued is, geologically speaking, very short, so that the present drainage is still in an undeveloped stage. However, many of the larger lakes have long since become filled with excellent peat and there are numerous deposits, a great many of which are extensive enough to warrant commercial and agricultural development. The field work and the analyses recorded in this report show that Ohio possesses excellent deposits of peat of good quality for fuel and other purposes.



Map showing distribution of peat deposits in Ohio. The deposits are represented on an exaggerated scale.

The area of peat land actually tested is about 150,000 acres. The government's estimate is 155,047 acres for Ohio, 625,999 for Indiana, 50,000 for Pennsylvania, 192,000 for Maryland, 800,000 for Virginia and 23,900 for West Virginia. The average thickness of peat in Ohio is about 10 feet. It is more than likely that the area previously mentioned forms only about 85 per cent. of the total for the State. At an early time the area of bog and marsh land was much larger, but with the settlement of the State many extensive areas have been burned over and drained. Only black-colored soils with a high humus content remain today to suggest the former location of such areas. In most of the bogs the material is sufficiently decayed for fuel; but in a few places it is notably coarser and better suited for purposes in which a fiber is desired. All of the peat land, however, can be successfully transformed into profit-producing tracts of great value. The conservation of material resources, especially of bogs, swamps and forests, is not only a part of the national program, but also a state issue as well. The movement toward the conservation of swamp and bog resources has already been launched in other states, and to render them productive is a problem of no mean importance.

In Ohio the peat area capable of utilization is near the eastern and middle-western markets and centers of population, and the development of it should be of immediate rather than distant importance. The available deposits, large and small, which are to be found in the State, represent an enormous amount of stored-up energy. Except for a single experimental plant near Plymouth, where peat is prepared as a "filler" in artificial fertilizers, these resources are at present undeveloped. The analyses given on subsequent pages and summarized in table 26 show that the peat of Ohio is not greatly different from that found elsewhere in thermal value, in ash content, and in the ingredients for use in agriculture.

The new processes in Europe for the manufacture and uses of peat are no longer considered in the experimental stage. Foreign peat appears to average somewhat lower in ash and consequently a little higher in thermal value, but the difference is not great, and especially is this true when compared to that from Ohio, Michigan and Indiana.

But even if this enormous acreage of bog land in Ohio cannot yield a profit from the peat industry, its reclamation for farm land is certainly a matter of great importance, and tillers of the soil must learn sooner or later the great value of it. Reclaimed bog and swamp lands under judicious treatment make the most fertile and valuable farms. Rich in humus, such soils should yield farm products without material soil exhaustion. If not of importance as a source of fuel or for agricultural development, then peat would be of great practical value as the most potent fertility factor in the improvement of the physical properties of soil, such as water-holding power, heat conductivity, and as organic matter for the lower forms of life beneficial to the soil (pp. 349–358). Owners of farms who have tracts of bog and marsh land should test them by boring to ascertain the depth of the deposit and to determine whether a stratum of marl or one of blue clay underlies the deposit. A post or carpenter's augur welded to detachable iron rods would serve admirably for the investigation.

There are many undrained depressions and partly filled lakes and ponds where water is standing permanently. They are the places where the formation of peat is still actively in process and in time may yield resources nearly as great as those now available.

CHAPTER III

DISCUSSION OF PEAT DEPOSITS BY COUNTIES

In the following account of the peat deposits in the various counties, the aim has not been to supply a separate report for each of the many peat bogs and swampy areas, for to do so would far exceed the available limits of this bulletin. The more detailed work of locating, describing, and testing each deposit must be left to the time when the demands will permit further peat investigations. In this chapter it has seemed desirable to supply information upon the better and larger deposits in each county, and upon their character and quality as shown by analyses and fuel tests. It was considered best to investigate only those bogs whose situation was convenient to transportation lines, and whose material was most favorable for commercial development. The description of local deposits includes, therefore, the approximate size of the bogs, the thickness of peat in different portions and its general physical and chemical character. In addition the flora was noted to determine what plants had been most active in the formation of the deposits.

The time and funds devoted to this investigation were limited, and although the writer has given unsparingly of his time, the results embodied here represent the information accumulated in the field while in the employ of the State during the summers of 1910 and 1911. It is scarcely necessary, therefore, to remark again that this report is only a preliminary one. Not more than a few days on the average have been devoted to the exploration of each of the counties. Though nearly every county has been studied, yet under the circumstances it was obviously impossible to complete a detailed and thorough investigation of each. It should not surprise the reader if many deposits have been overlooked, or are not found described in the text. A detailed field study is scarcely desirable so long as the peat industry in the United States is still in its infancy.

The order in which the counties are described is alphabetical. This is necessarily arbitrary and cannot serve well for an illustration of the progressive vegetation changes, or for the several types of bogs found in the State. An account of the conditions of growth, the manner in which peat deposits are formed, and the most important natural plant associations which establish themselves in a rotation and advance upon the lakes and ponds in Ohio have been given in Chapters V and VI and in part III of this volume.

Method of Testing Peat Bogs.—In all cases the samples analyzed consisted of a number of test borings which were made with a sampling instrument devised by Davis. The instrument is so constructed that a number of two-foot sections of half-inch pipe can be readily connected by couplings. The lengths permit an easy estimation of the depth reached from which the sample of peat is required. One of the sections has a short transverse handle at one end. Another section has a brass cylinder about an inch in diameter, and about nine inches long, which can be connected to any number of pipes and pushed down to the depth desired. The cylinder is provided with a metal plunger and a spring catch, so that the former can be partly withdrawn from its inclosing metal cylinder at the desired depth, locked in that position and filled with peat by short up-and-down movements. The cylinder thus protects the sample completely from any mixture with other peat during withdrawal. The sample is then ejected from the cylinder by forcing in the plunger, and collected in a cloth bag, or where determinations of the per cent. of water in the peat are desired, in well corked glass bottles.

Chemical Analyses of Peat Samples.—Since almost all of the chemical analyses and determinations of fuel values were made in the Pittsburgh laboratory of the United States Bureau of Mines, the data are readily comparable with those showing the quality of peat from other states, and with the more general investigations of the fuels of the United States. The determinations here given include the analyses of peat samples in an air-dried and in a moisture-free or kiln-dried condition. The analyses show the heating value, the percentage of moisture, volatile combustible matter, fixed carbon, ash, nitrogen, sulphur, and, in a few cases, iron. The sulphur and nitrogen are part of the volatile matter and are determined separately. The volatile matter, fixed carbon and ash together make 100 per cent.

The volatile matter represents the material which is given off during heating in a covered dish. The fixed carbon is in part the peat-coke or charcoal which is not expelled during heating, but requires a higher temperature for consumption; the ash is the mineral matter left behind and with the exception of a few cases is not further analyzed. The percentage of fixed carbon is calculated from the difference between the weight of the ash and that of the peat coke. The percentage of nitrogen gives an indication of the value of the peat for agricultural purposes. Sulphur and iron are determined on account of the objectionable feature which an excess of these constituents has when the material is used for various chemical purposes.

The thermal or fuel value is given in two units: (1) the calorie, which is the quantity of heat necessary to raise the temperature of one kilogram of water one degree centigrade, and (2) the British thermal unit, abbreviated B. t. u., which is the quantity of heat required to raise the temperature of a pound of water one degree Fahrenheit. A discussion of the analyses will be found on page 152 and in Chapter XI dealing with the chemistry of peat.

ALLEN COUNTY

In the early history of the State, this county presented the features common to the "Black Swamp" (p. 104). Formerly Monroe Township had small areas of cranberry marsh, and remains of beaver dams are still numerous in Richland Township. The marsh land containing peat has been under cultivation for a long time. The peat tracts are usually very shallow and now contain too great a percentage of mineral matter to have any value for fuel. In the well drained areas the vegetable matter is rapidly undergoing decomposition. Where the peat is dry it is structureless, compact and black in color, rather plastic, and has been transformed more or less completely into humus. The flat and prairie-like tracts of sections 11, 12, 13 and 14 in Auglaize Township, and in the vicinity of Amherst in Perry Township, have this character. The humus content of the soil has been decreased by constant cultivation, tillage, cropping and occasional burning until the soil has become largely a black peaty clay loam of great fertility. The peat runs high in ash, the percentage varying from 53 to 65. The leading impurity is clay.

ASHLAND COUNTY

On the Ohio divide several small lakes and marshes occupy a small area of the original table land which has since been deeply eroded and diversified. The accumulation of vegetable matter usually overlies an earlier deposition of bowlder clay or a laminated variety.

Several townships, as Orange, Montgomery, Milton and Mifflin, have broad areas of level clay land, and, though traversed by small streams, the drainage is imperfect. These water plains spread out into wide valleys and until recently were marshy with a vegetation primarily of grasses, alders and swamp oak. The areas are now largely under cultivation. On account of the prevailing high percentage of ash (50 to 60) the heat value runs low.. The best use of these soils is for agricultural purposes.

CLEAR CREEK TOWNSHIP

The two Savannah lakes occupy the highest part of the divide, but lie in a valley (1,024 feet) of preglacial origin. The larger of the two has an estimated area of about 160 acres, and the smaller one, which lies adjacent, covers a surface of about 80 acres. Both are said to be quite deep, but the bottom is being silted up from the wash of the hills. The growth of the vegetation accumulates mostly in shallow water, and is, therefore, of no considerable depth. The vegetation differs but little from that around the smaller lakes of the neighboring counties. South of the divide the surface is covered with drift in isolated ridges and hills. The low depressions contain a number of peat deposits, but they are usually of too small extent for commercial purposes.

LAKE TOWNSHIP

Mud Lake.—The Mud Lake peat bog on section 23, one and one-half miles northwest of Lakeville, may be considered as fairly representative of the better grade of deposits. The area is estimated at about six acres, and the depth probably averages at least 18 feet. A considerable number of borings were made which show that the peat is not well humified, but is otherwise fairly uniform in quality. At the depth of 3 feet the material is dark brown, compact and fibrous, becoming lighter brown and more plastic at the 5-foot level. Below this the peat is again coarsely fibrous, reddish brown, alternating with several compact layers of a grayish brown variety. At a depth of 17 feet the material is greenish and distinctly laminated and consists largely of grasses and sedges. No samples were taken below a depth of 18 feet.

The mixed peat, sample No. 73, taken from the land of E. Horner, gives the following analysis when air-dried and then made absolutely dry by heating to constant weight:

Analysis No. 73

		Air-dried.	Moisture free.
Moisture		7.14	-------
Volatile matter		62.60	67.42
Fixed carbon		23.12	24.91
Ash		7.14	7.67
Nitrogen		2.21	2.39
Sulphur		0.25	0.28
Iron		0.36	0.39
Calorific value	Calories	4681.00	5039.00
	B. t. u	8426.00	9070.00

The analysis indicates that the deposit is low in ash and of high thermal value.

On considerable areas around the margin of the bog the peat is grown over with maple (*Acer rubrum*), poison sumach (*Rhus vernix*), arrowwood (*Viburnum sp.*), high-bush blueberry (*Vaccinium corymbosum*), and other shrubs, but alders are not present. The part nearer the open water is intermixed with cranberry (*Oxycoccus = Vaccinium macrocarpon*), bog mosses and aquatic plants. The vegetation has essentially the following composition, details of which are given in Chapter VI: The semi-aquatic association is represented by the water lilies and knotweeds; the border succession consists of the rose-mallow (*Hibiscus moscheutos*) with occasional cattail (*Typha latifolia*); loose-strife (*Decodon verticillatus*) was not observed. The bog meadow is a cranberry-sphagnum association with occasional clumps of the small huckleberry (*Gaylussacia baccata = resinosa*). The shrubs consist mainly of arrowwood with winterberry (*Ilex verticillata*), chokeberry (*Aronia = Pyrus arbutifolia*), blueberry and poison sumach. In the older part of the shrub zone there is a well defined maple-ash association.

The bog is favorably located. The nearest shipping point is Lakeville, about 1½ miles southeast on the Pennsylvania line (Pittsburg, Ft. Wayne & Chicago Railway).

The complete drainage of the bog is impracticable, and the peat will therefore have to be excavated by dredging or by pumping.

A smaller deposit of about 100 acres lies in section 4 of Mifflin Township and extends over into Richland County.

ASHTABULA COUNTY

By far the greater portion of this county is a broad level plain of stiff clay. The old "lake ridges" and terraces are well defined in the northern portion of the county. Where exposed by railroad cuts, remains of old swamps can be seen containing fragments of coniferous wood and in places deposits of bog iron. Winds gradually carried beach sand over the crest of the ridge into the swamp basin, burying it in time to a depth of about six feet.

South of the lake ridges the surface is gently undulating. It has been eroded by water and modified by occasional deposits of gravel from the drift. The stiff clay derived from the decomposition of the Erie shale is very retentive and any excess of rainfall is generally conducive to the development of marsh areas.

ANDOVER TOWNSHIP

The Pymatuning Swamp.—This bog covers an area approximately 5 miles long and averaging about one mile in width, but the greater part is in Pennsylvania. About 500 acres of it lie in Ohio. The area and location are shown on the Andover sheet of the United States Geological Survey. The headwaters of the Shenango River have their source in this bog.

The Pymatuning swamp at its southern end, about 3 miles east of Andover, has the characteristics of an inundated river bottom and is a prairie-like marsh. The area is now used for pasture. The peat is dark brown, well decomposed, but silty and averages 8 feet in depth. Its best utilization lies in agricultural possibilities.

The vegetation of this area shows, as has been stated, a tendency toward the development of a pasture association. It is difficult to characterize the succession otherwise because of the number of weeds and typical marsh plants present. The latter consist principally of wool grass (*Scirpus cyperinus*) with water pepper, lady's thumb and others (*Polygonum hydropiperoides, P. persicaria, P. pennsylvanicum*). The secondary or less common species are ditch stonecrop (*Penthorum sedoides*), sensitive fern (*Onoclea sensibilis*), sedges (*Cyperus strigosus*), yellow dock (*Rumex crispus*), white grass (*Leersia virginica*), cleavers (*Galium trifidum*), bur reed (*Sparganium eurycarpum*), water purslane (*Ludvigia palustris*), false nettle (*Boehmeria cylindrica*), water plantain (*Alisma plantago-aquatica*), marsh speedwell (*Veronica scutellata*), bur marigold (*Bidens laevis*) and an occasional willow

(*Salix nigra, S. lucida*). Farther north on the Ohio side of the State line the cat-tail (*Typha latifolia*) with various species of arrow head (*Sagittaria sp.*) predominate in the wet places.

Still farther north in Richmond Township, wooded conditions prevail which have been interfered with considerably by fire and the cutting of timber. Tamarack and yellow birch (*Betula lutea*) must have made up the bulk of the original forest, for the relative abundance of birch is considerably greater than that of any other tree. Aspens, closely followed by red maple and the black ash, have started a secondary succession. It varies in density from an almost impenetrable thicket to an open wood with abundant undergrowth.

In the northeastern corner of Andover Township is found a narrow strip of bog in which the tamarack forms an almost continuous and nearly pure growth. Several groves of this show but little admixture of deciduous trees and the timber is in good condition. The trees average about 40 years or more in age. There is a slight admixture of white pine, yellow birch, and hemlock and an occasional red maple. The undergrowth is fairly dense. The mountain holly (*Nemopanthus = Illicoides mucronata*) and chokeberry (*Pyrus melanocarpa = Aronia nigra* reach in places a height of 25 feet, forming a distinct secondary vertical layer. Beneath them are the high-bush blueberry (*Vaccinium corymbosum*), arrowwood (*Viburnum cassinoides, V. dentatum*), black huckleberry (*Gaylussacia resinosa = baccata*), flowering ferns (*Osmunda cinnamomea, O. regalis*), sensitive fern (*Onoclea sensibilis*), swamp honeysuckle (*Azalea = Rhododendron viscosum*), black alder (*Ilex verticillata*), and the yew (*Taxus canadensis*). The painted trillium (*Trillium undulatum*), wild sarsaparilla (*Aralia nudicaulis*), shield fern (*Aspidium = Dryopteris noveboracensis, D. goldieana, D. spinulosa*) and the woodbine (*Ampelopsis = Psedera quinquefolia*) are not uncommon. They form a mixed tertiary layer with but slight reference to substratum conditions. The smaller species are club mosses (*Lycopodium dendroideum*), white fringed orchid (*Habenaria blephariglottis*), clintonia (*Clintonia borealis*), goldthread (*Coptis trifolia*), Indian cucumber root (*Medeola virginiana*), lady's slipper (*Cypripedium acaule*), dalibarda (*Dalibarda repens*). The little May flower (*Maianthemum = Unifolium canadense*) and the bog mosses (*Sphagnum* and *Polytrichum*) occur scattered throughout as a substratum cover. They are found on prostrate trunks and on the loose covering consisting principally of tamarack needles.

Testborings revealed a brown, well decomposed peat with fragments of wood. Its thickness is 5 feet and it rests on a grayish blue clay.

In a number of places severe fires have swept over the area. This was about 20 years ago when large tamarack groves were almost completely destroyed. Since then a fairly good growth of the same tree has started, but shrubs have made the most rapid growth and now present an interesting stage rarely found in Ohio.

The open places are occupied by a dense growth of leather leaf (*Chamaedaphne calyculata*) which reaches everywhere a height of 3 feet. Associated with it are occasional ferns (*Osmunda cinnamomea, O. regalis*) and underneath them a ground cover of *Sphagnum* and *Polytrichum* overgrown with prostrate bramble (*Rubus hispidus*), the ascending bramble (*R. setosus*) and wintergreen (*Gaultheria procumbens*). Scattered like islands throughout the leather leaf association, are dense thickets of tall shrubs averaging a height of 7 or 8 feet. The mountain holly is most abundant and with it are chokeberry, the high-bush blueberry, and an occasional alder. In several places the thickets are extensive and altogether impenetrable.

Among the leather leaf association in the better lighted, open and moister places occur low blueberry (*Vaccinium pennsylvanicum*), bartonia (*Bartonia virginica*), and some characteristic forms like the sedges (*Carex trisperma, C. tenella*), cotton grass (*Eriophorum virginicum*) and sphagnum mosses with the round-leaved sundew (*Drosera rotundifolia*). This is merely a passing phase of an early cranberry-sphagnum association; the open places are to be looked upon as remnants of a former vegetation cover rather than as characteristics of a fire succession. In shallow depressions, which usually result from deep-burning fires or from the uprooting and fall of trees, the plants most common are cattails and water arum.

Crossing into Pennsylvania at a point two miles east of Padanarum, the northern end of the Pymatuning swamp has a vegetation cover which consists of a relatively well developed Maple-black Ash-Elm association. Tamarack, hemlock and white pine occur rarely. Magnolias (*Magnolia acuminata*) are observed frequently. The undergrowth noted contains among other plants, the spice-bush (*Benzoin aestivale*), swamp honeysuckle (*Azalea* = *Rhododendron viscosum*), dogwood (*Cornus circinata*), lizard's tail (*Saururus cernuus*), touch-me-not (*Impatiens biflora*) and others. This type of forest represents the general character of a mature phase of bog successions.

DORSET TOWNSHIP

Leon Bog.—In the southeast corner of Dorset Township, about 2½ miles west of Leon, is a bog of considerable proportions, but the exact limits were not determined. It is claimed that the area approximates 300 acres. The location is shown on the Andover sheet of the United States Geological Survey. The bog is favorably located on the Lake Shore and Michigan Southern Railroad, but is very heavily wooded with black ash, maple, elm and others. The vegetation tenanting the deposit represents a mature phase of bog forest association. Near the railroad is an area of several acres which has been damaged by fire. On the unburned tract the thickness of peat averages 4½ feet, with occasional pockets which are considerably deeper. The wooded character of the area and the abundance of logs buried in the peat would increase the cost of exploitation. The headwaters of Pymatuning and Mill creeks, the former flowing south and the latter north, have their source in this swamp. An artificial embankment, supposedly formed by beavers, extends across the middle of it. A smaller bog similar in character lies a mile north, but time did not permit a study of it, or of the bogs in Morgan Township.

ORWELL TOWNSHIP

Orwell Tamarack Bog.—The Orwell bog is a part of an extensive peat deposit which extends from Orwell Township south into Bloomfield within Trumbull County, a distance of more than 7 miles. The Ashtabula branch of the Pennsylvania Railroad passes within 1½ miles to the west of the deposit. The area and location are shown on the Jefferson sheet of the United States Geological Survey (Fig. 1). The part within this county comprises about 1,000 acres and lies in a depression formerly occupied by an old lake which was gradually filled by plants. The peat is brown, well decomposed, though slightly admixed with coarsely fibrous material and is in part formed by remains of sedges, grasses and aquatic plants. Large quantities of roots, charred logs and fallen trees are intermingled with the peat at the 3-foot level. The thickness of the deposit varies from 3 to 5 feet. It rests on a grayish blue clay.

The greater part of the bog is heavily wooded with tamarack, yellow birch, red maple and black ash; the shrubs beneath the trees are arrowwood, chokeberry, poison sumach, high-bush blueberry and others; a lower layer of huckleberries, royal and cinnamon fern, lizard's tail, touch-me-not with dodder and a number of other herbaceous plants, is found underneath them. The ground layer consists in part

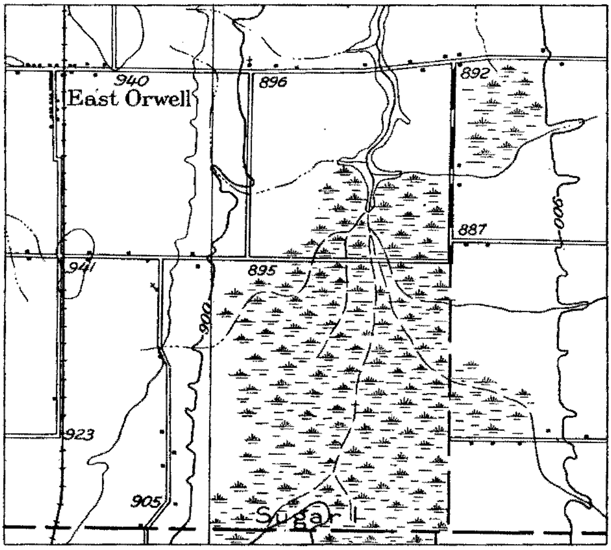


Fig. 1.—Map showing location and area of Orwell Bog, Ashtabula County. Scale, 1 inch = 1 mile (2.5 cm = 1.6 km).

of sphagnum mosses, polytrichum, mayflower and several more. The vegetation on the whole so closely resembles that of the Pymatuning bog that much of the description given of it will serve equally well here.

Natural valleys are gradually draining the area. The settling of the peat resulting from the drainage is shown by the large roots of trees exposed in a network which makes the bog almost impassable in many places.

The quantity and purity of the peat is not such as to render the bog commercially important. Its heavily wooded nature and the fallen and charred timber beneath the surface layer hardly permit of manufacturing machine-peat on any scale. However, if the wood is removed, the remaining part can be cut by hand and utilized for domestic purposes. The deposit, now practically worthless, would be considerably enhanced if the bog were drained and the land utilized for agricultural purposes.

Analysis No. 44 represents a composite sample of peat from a part of the bog covered with shrubs, alder and maple:

Analysis No. 44

		Air-dried.	Moisture-free.
Moisture		9.08	-------
Volatile matter		57.51	63.24
Fixed carbon		23.78	26.18
Ash		9.63	10.58
Nitrogen		2.23	2.45
Sulphur		0.41	0.46
Calorific value	Calories	4531.00	4981.00
	B. t. u.	8156.00	8966.00

The analysis shows a relatively high ash content, but a good thermal value. The ash indicates that the creeks which traverse the area carried more silt from the neighboring hills during the earlier stages of bog growth than at present. The upper layers of peat are considerably purer than the lower. Possibly the percentage of ash may be lower in other parts of the bog.

PLYMOUTH TOWNSHIP

Two well drained bogs, midway between the cities of Ashtabula and Jefferson, covering an area of about 2,000 acres, are now almost wholly under cultivation. The area and location of the deposits are shown on the Ashtabula sheet of the United States Geological Survey. The larger of these is over 3 miles long and averages one-half mile in width. Coffee and Center creeks traverse the area westerly and empty into Grand River near Austinburg. Borings were so distributed as to test all parts of the bogs, but failed to show more than a few inches of peat. Several pockets and depressions were encountered in which the thickness is 3½ feet. The peat is well decomposed, dark brown to black, and has been changed to humus by constant cultivation. The deposit runs high in ash (80 to 85 per cent.) and the leading impurity is a sandy clay.

The deposit had its origin in the causes which raised the two ridges traversing the northern part of the county. Between these the soil in many places is a black, rich muck. Evidently the deposit represents a former shallow basin which became filled with vegetation at a time when the water of the lake was held back by the south ridge.

WAYNE TOWNSHIP

There is a narrow belt of peaty soil approximating 500 acres along Pymatuning Creek in Wayne Township. The area and location are shown on the Andover sheet of the United States Geological Survey. The creek and its numerous smaller tributaries flowing through the deposit carry silt, and hence the peaty substratum in this locality contains sandy layers which represent seasons of excessive floods. In some places the depth of peat averages only a few inches, while in others occasional pockets occur with a thickness of several feet. The samples frequently contained more than 50 per cent. of mineral matter and were not regarded worthy of chemical analysis or test for fuel value. In the townships of Trumbull, Morgan, and Hartsgrove are heavily wooded deposits of peaty soil varying in area between 100 and 300 acres. The character of the material is not suitable for anything but agricultural purposes.

AUGLAIZE COUNTY

This county in places is quite flat with many features of the Black Swamp (p. 104). More frequently it is undulating with three morainal ridges and many irregular successions of gravelly knolls. The drainage is imperfect over considerable areas. The eastern part of the county had formerly extensive wet grassy prairies on which from several inches to a foot or more of water was standing during the wet months of the year. These areas had a peaty soil resting on a sandy clay, but free access to the air and cultivation have reduced the deposit to a shallow layer of humus. Beds of peat and marl are common in the county, but they are small—from one to five acres in area. The thickness of the peat deposits varies from 2 to 8 feet. Testborings indicate a well decomposed, but often silty variety, with a percentage of ash so high that further examination is unnecessary. The deposits might be valuable for local commercial use. Almost all are now under cultivation. A few basins have been cleared and are used as fish ponds.

The vegetation on uncleared portions of peaty soil consists principally of sedges and grasses, willow bushes and others. The following plants were found: Willows (*Salix discolor, S. sericea*), dogwood (*Cornus stolonifera*), vetchling (*Lathyrus palustris*), shield fern (*Aspidium = Dryopteris thelypteris*), shooting star (*Dodecatheon meadia*), parnassus (*Parnassia caroliniana*), sedges (*Carex lurida, C. vulpinoidea, C. scirpoidea*), spike rush (*Eleocharis obtusa*), soft rush (*Juncus effusus, J. tenuis*), bulrush (*Scirpus atrovirens*) and horsetail (*Equisetum arvense*).

Remains of the mastodon are found in many of the peat bogs and marshes throughout the county. Nine specimens of this great animal and two of the rodent, *Castoroides ohioensis*, have been exhumed. The following account is quoted in large part from C. W. Williamson's History of Auglaize County, 1905:

(1) A mastodon was found in 1870 in Clay Township in the Muchinippi swamp, two and one-half miles east of the village of St. Johns. The depth of the swamp at the point at which the discovery was made is about eight feet, of which the upper third is of peat, and the remainder of marl or marly clay. The bones were found in a posture natural to a quadruped when sinking in the mire. The head and tusks were thrown upward and the right forefoot thrown forward as in the act of walking.

(2) The second mastodon was found in section 4 of Clay Township, about the same time.

(3) A third mastodon was discovered by Mr. S. Craig, in 1878, while engaged in surveying section 19 in Washington Township. No careful search for the skeleton has yet been made.

(4) The remains of the fourth mastodon were discovered about fifteen years ago in a ditch excavation in section 33 in Duchouquet swamp. The remains were so badly decayed that they crumbled upon exposure to the air.

(5) About eighteen years ago a mastodon was discovered in digging a ditch in Wayne Township. The writer saw the terminal portion of one of the tusks a few years after it was found.

(6) In 1881 a mastodon was unearthed in digging a ditch in Union Township. It, too, fell to pieces upon exposure to the air.

(7) A report of the discovery of a mastodon in Salem Township has been made to the writer, but the particulars have not been given.

(8) In 1891 a mastodon was discovered by some laborers engaged in deepening and widening the bed of a creek, extending through section 22 of Duchouquet Township. The tusks, which projected across the ditch, were severed by the workmen and carried to Logan County. No attempt has yet been made to recover the body of the animal.

(9) In 1894, a mastodon calf was discovered by J. Nuss, in section 29, Pusheta Township, imbedded in a layer of muck at the bottom of a circular pond. For the first time in many years the pond was dry, and the owner decided to deepen and convert it into a fish-pond. In removing the humus the skeleton was uncovered, and it was the most complete that has been found in this or adjoining counties. It measured about three feet in height and approximately four in length. Its tusks were about one foot long. The discoverer kept it two or three years expecting to receive a high price for it, but at the end of that time it was worthless from long exposure to the air.

The head of a great rodent, *Castoroides ohioensis*, with the exception of the lower jaw, was found buried at the margin of a bog in section 29, Washington Township, in 1889. An investigation disclosed a bed of humus, resting on a bed of gravel, of excellent quality for road-making. Soon after the discovery, the gravel-bed was purchased by the village council of New Knoxville for gravelling the streets of that corporation. In removing the carbonaceous deposit near the margin of the pond, on the south side the habitation of the rodent was uncovered. The house was about eight feet square and between three and four feet in height. The willow poles of which the pen was constructed, were about three inches in diameter and were laid in the manner in which beaver houses are constructed at the present time. Within this house the great beaver died. After his death his domicile was tenanted by wolves and other carniverous animals, as was shown by the bones of deer and other animals strewn over the floor. The body of the modern beaver is about three feet long, exclusive of the tail, whilst Castoroides ohioensis was over five feet in length. It should be noted that this animal is not related to the modern beaver but to the Coypu rat of South America.

CHAMPAIGN COUNTY

URBANA TOWNSHIP

Dallas Arbor Vitae Bog.—The most interesting of the many kinds of bogs in Ohio is a cedar bog near Urbana, in Champaign County, about 40 miles west of Columbus. In a few places the topography is hilly, and peat deposits occur in the depressions. As a whole, however, the general form is that of a broad shallow trough, lying north and south. Mad River runs through the middle of it and drains the main body of the territory.

On the east side of Mad River, in the southeastern part of the township of the same name, in sections 31 and 32, and extending largely over into Urbana Township, is a tract of land known as the Dallas cedar swamp. It is about 6 miles south of Urbana, and easily reached by means of the Ohio Electric Railway, the Erie Railroad and the Big Four (C. C. C. & St. L. Ry.) The cedar swamp is a part of an area of cleared bog, comprising today about 600 acres, but formerly covering approximately 7,000 acres. On a small portion of land owned by M. and G. L. Dallas occur, as described below, groves of arbor vitae (*Thuja occidentalis*) in a good state of preservation. The groves occupy a habitat near which the soil water is derived from cold springs along the poorly drained valley. A considerable number of soundings were made which disclosed for the first two feet a blackish brown, compact, well decomposed, non-fibrous peat. At the three foot level the peat appeared dark brown, somewhat fibrous, with a considerable admixture of marl below. A number of well preserved logs and branches were encountered. At four feet the peat appeared brown and compact, but fibrous in texture with fragments of rhizomes and roots. At the 5-foot level the sounding instrument encountered a coarse gravel with stones showing glacial striations. This rested on beds of quicksand. Analysis No. 60 represents a composite sample of peat from this bog.

Analysis No. 60

		Air-dried.	Moisture-free.
Moisture		10.73	-------
Volatile matter		50.89	57.01
Fixed carbon		23.59	26.43
Ash		14.79	16.56
Nitrogen		2.29	2.56
Sulphur		1.08	1.21
Calorific value	Calories	3753.00	4204.00
	B. t. u	6755.00	7567.00

The bog harbors a unique dependent flora which long throve unmolested and was once a favorable resort for botanists. Now the cedars and the accompanying undergrowth are rapidly disappearing as the clearing of the area nears completion. The indications are that in a few years the last vestige of this interesting aggregation of plants will be destroyed.

This type of bog is distinctly northern in its distribution and has not been observed by previous writers to occur south of the central part of Michigan. The brief time which could be given to the locality made a more detailed study and the mapping of the area impracticable. Yet the notes and records made have revealed a considerable number of species hitherto supposed to be confined to states north of Ohio.

In several places the groves of arbor vitae are dense pure stands or facies with scarcely any undergrowth. The association has only a single vertical layer in which the lowest branches of the trees bear a common spacial relation to light. The ground is littered with cedar foliage and only occasionally small sprouts of the chokeberry (*Aronia arbutifolia*), and stunted seedlings of yellow poplar (*Liriodendron tulipifera*) or small plants of the spice bush (*Benzoin aestivale*), alders, and woodbine are visible; generally there are no members of a subordinate species other than a few mosses and liverworts. In more open stands in which the effects of fire and cuttings are still present the arbor vitae is found in association with the red maple (*Acer rubrum*), yellow poplar (*Liriodendron tulipifera*), black ash (*Fraxinus nigra*), white walnut (*Juglans cinerea*), sycamore (*Platanus occidentalis*), and wild cherry (*Prunus* *serotina*). The undergrowth is not only numerous in species but of exceptional height and in five layers. The poison sumach (*Rhus vernix*) reaches frequently a height of twenty-five feet. Other members of this structural part of the association, and determining more specifically the physiognomy of the layer, are the alders (*Alnus incana, A. rugosa*), the winter-berry (*Ilex verticillata*), the chokeberry (*Aronia arbutifolia*), and the round-leaved dogwood (*Cornus circinata*). The inferior layers which seem entirely determined by the density of the mixture of facies are really overlapping communities of woodland and bog plants. There seems scarcely any relation to habitat factors. Seedlings and sprouts occur in all directions, in various degrees of abundance, and only the less hardy plants lose ground, thus producing examples of an indiscriminate alternation. The spice bush (*Benzoin aestivale*) is only of relatively less importance in the (second) stratum of bushes to the red bud (*Cercis canadensis*) and the elderberry (*Sambucus canadensis*).

The subordinate position with regard to the taller species is occupied by the cinnamon fern (*Osmunda cinnamomea*), the meadow rue (*Thalictrum dasycarpum*), the spikenard (*Aralia racemosa*), the bladder fern (*Cystopteris bulbifera*), and touch-me-not (*Impatiens sp.*). With them in varying abundance occur, as a lower herbaceous layer, the maiden-hair fern (*Adiantum pedatum*), the dwarf raspberry (*Rubus triflorus*), wood ferns (*Dryopteris = Aspidium cristatum*), miterwort (*Mitella diphylla*), wakerobin (*Trillium erectum, T. grandiflorum*), false Solomon's seal (*Smilacina trifolia*), violet (*Viola blanda*), the star flower (*Trientalis americana*), the Indian cucumber-root (*Medeola virginiana*), manna grass (*Glyceria torreyana*), and others.

In many places the various shrub layers immediately below the trees interpose as dense screens. These are often of sufficient density to reduce the light to a diffuseness which leads to frequent modification and a consequent rearrangement of the individual plants in the ground stratum. The number of such plants present is not large; they are all past flowering when shade conditions become extreme. The little mayflower (*Maianthemum canadense*) and various mosses and liverworts are the more resistant members of the living ground cover; they tend to disappear only when the shade condition approaches a light value similar to that of the pure stands of cedar.

To the east of the mature association and adjoining it is an open area; in it occur a number of low wet places. The water of the cold springs is overcharged with carbonate of lime. The average soil moisture content is near saturation, and the soil temperature uniformly low throughout the year. In other places the water content is not quite so high, but higher usually than in any of the soils frequented by the cedars. Testborings indicate a surface layer of black non-fibrous peat about two feet thick, resting on a cream-colored, fine-grained marl, three feet in depth and underlaid by sandy gravel. The marl is frequently of the nature of calcareous tufa. In the wetter habitat the plant association resembles that of an open sedge zone. The dominant plants are the rushes, *Juncus brachycephalus, Eleocharis obtusa, E. palustris*, and *Scirpus americanus*. The physiognomy changes in places on account of an admixture of shield fern (*Aspidium = Dryopteris thelypteris*) and the parnassus (*Parnassia caroliniana*), with an occasional lizard's tail (*Saururus cernuus*), some goldenrods (*Solidago riddellii, S. ohioensis*), the Canadian burnet (*Sanguisorba canadensis*), twayblade (*Liparis loeselii*), water avens (*Geum rivale*), millet grass (*Milium effusum*), the marsh bell flower (*Campanula aparinoides*), lousewort (*Pedicularis lanceolata*), the golden ragwort (*Senecio aureus*) and swamp asters (*Aster puniceus, var. lucidulum*). Until recently orchids (*Habenaria psycodes*) and lady slippers (*Cypripedium hirsutum, C. parviflorum*) were not uncommon.

Nearer the cedar groves a low shrub society appears, among which the shrubby cinquefoil (*Potentilla fruticosa*), the bog birch (*Betula pumila*), several willows (*Salix discolor, S. petiolaris*), the buckthorn (*Rhamnus alnifolia*), and dogwoods (*Cornus stolonifera, C. alternifolia*), are the more characteristic members. The ground cover is almost throughout one of mosses, such as *Hedwigia albicans, Anomodon ros-*

tratus, and a species of *Chara*. In this association lateral zonation is most clearly in evidence and arises in part from the characteristic growth form of the respective species, and in part from the physical features of the habitat. Of the latter the factor chiefly concerned is the water content of the soil. The essential connection between this is evident where springs are the source of shallow pools. Tension lines in the vegetation (ecotones) are not well marked, however. The zones are too often incomplete or obscure. There is in consequence more or less of a transition from the ground layer of mats of mosses and algae to the lower grass and herbaceous layer and to the tertiary layer of bushes and shrubs.

The habitat across the road and south of the areas just described, bears less resemblance to extremes in water content. The cedars are of less mature age and size, and deciduous invaders are still lacking. Next to the arbor vitae the predominant trees are the yellow poplar and the red maple. The flora seems more distinctly related to a transition stage. This may be due to a former partial clearing of the area. The young cedar trees average a height of ten to fifteen feet, and appear to be in about equal abundance. The shrubs resemble those of open bogs, *Aronia arbutifolia* and *Ilex verticillata* being the most notable species. *Betula pumila* and *Potentilla fruticosa* are rare. The shrubs form a vertical layer nearly equal in height to the cedars. The interesting peculiarity of the ground layer is the frequent occurrence of mats of sphagnum (*Sphagnum cymbifolium, S. acutifolium*) with the round-leafed sundew (*Drosera rotundifolia*) clinging around the stems of small bushes of huckleberry (*Gaylussacia resinosa = baccata*). These hummocks are often overgrown with the prostrate blackberry (*Rubus hispidus*). *Parnassia caroliniana*, the fringed gentian (*Gentiana circinata*), the marsh bellflower (*Campanula aparinoides*), violets (*Viola blanda, V. arenaria*) and St. John's-wort (*Hypericum prolificum*) with the great lobelia (*Lobelia siphilitica*), and a similar but slender dwarf form (*Lobelia spicata*) are found indiscriminately, but usually near small pools in which the small bladderwort (*Utricularia minor*), mosses (*Hypnums*) and algae (*Chara sp.*), are some of the frequent species. The cattails (*Typha latifolia*) are still of sparse growth.

Adjoining this open association is a clearing, now used for pasture, which was formerly burned over. The peat soil is black in color, non-fibrous but rather wet. The entire cleared area is densely covered with the shrubby cinquefoil (*Potentilla fruticosa*) averaging a height between three and four feet (Plate VII. B). In a few undisturbed places a succession is indicated with arbor vitae as the dominant tree. Seedlings of red maple and yellow poplar are close associates. The succession is virtually an indeterminate rejuvenation, that is, the habitat still dominates the vegetation. The degree of stabilization still gives expression to xerophytic forms. The physical conditions which are changing extremely slowly, remain unfavorable to invaders, and tend to preserve many of the most important early vegetation stages. The persistence and dominance of the cedar association in this latitude follow for these reasons, but partly also on account of the predominance of the trees present; for the association itself must be considered as an essential, active factor in furnishing seeds, and in eliminating diversity. Largely, however, the dominance is an adjustment to the available soil water content. A competition with seedlings of deciduous trees other than the yellow poplar and red maple does not seem to ensue, although the light is favorable. A relation of seed production to ecesis, that is, to germination and establishment, is nowhere obvious. The various species of deciduous trees have a larger seed production and more effective dissemination contrivances, but so far as the actual number of seedlings is concerned the relative absence of them suggests some edaphic agency in selective operation. There is some sort of correspondence in the arbor vitae, in plasticity of function, or in habitat form, to the life relations of the soil. Definite conclusions, however, can only be reached by experimental studies. The field observations would indicate that the nature of the primeval forest of this region did not consist of a combination of trees such as now exist on the drier areas described above. The deciduous arborescent group of plants in which the sequence is the development to the deciduous climax forest, is at present decidedly a mixture, and though a closed association, yet one whose original members were allied more to the northern cedar bogs.

JOHNSON TOWNSHIP

Mosquito Lake.—This is an irregular body of water, which until recently comprised about sixty acres in the northern part of Johnson Township. Encircling the lake and extending northwest along Mosquito Creek is a peaty area of about 300 acres. The deposit contains a fine-grained, well humified peat, varying between one and six feet in thickness and resting on a bluish colored shell marl that is underlaid with drift. As a result of extensive erosion and drainage the deposit in many places is covered with soil washed in from the adjoining hills. The difficulty in digging and the considerable distance of the deposit from the railroad, make it improbable that it will ever be worked extensively for commercial purposes. No analyses were made of the samples.

RUSH TOWNSHIP

Brush Lake.—The only visible deep accumulations of peat are in sheltered places. It is sometimes 10 feet or more in thickness, and the upper layers are rather coarse and fibrous, but toward the center of the lake it is finer grained. The peat is sandy in many places. The deposit is too small as yet to be of much importance and no chemical analysis was made of the samples collected. The vegetation in and around the lake is arranged in more or less concentric zones, corresponding to the depth of the water. The characteristic plants and their arrangement will be found described in the proceedings of the Ohio State Academy of Science.[1]

SALEM TOWNSHIP

In the early history of the county this township, as well as Goshen, Harrison, Union and Wayne, had large areas which were covered by a dense growth of prairie grasses, rushes and sedges. The areas have been tiled and drained and now contain a firm, well settled peat varying in thickness from a few inches to a foot. The upper layers are well humified and hence are of greater agricultural than commercial value.

CLARK COUNTY

This county is dotted with knolls and ridges which often enclose basin-shaped depressions of small extent. The physical features of the county are principally due to the present drainage system. The valley

[1]Schaffner, J. H., Ecological Study of Brush Lake; Proc. Ohio Acad. Sci., Vol. IV., 1904, pp. 151-165.

of Mad River with its swampy borders—locally called "cat-head prairies," which consist largely of the accumulation of plants like the cattail, rushes and grasses—is the most marked topographical feature of the county. The tributaries of this stream share in this peculiarity, meandering in broad flat plains with shallow swampy borders. The deposits of vegetable matter are rarely very thick, for previous to the settlement by immigrants the Indians set fire each year to the grassy prairies to facilitate hunting.

The northeastern portion of the city of Springfield, between sections 29 and 30, rests on a peat deposit of good quality, varying between eight and twelve feet in thickness. The area approximates over 100 acres. The peat is brown, fibrous and contains a relatively small quantity of mineral matter.

In Bethel Township near Medway, in sections 25 and 26, are several lakes fed chiefly by springs. There are around them deposits of blackish, well decomposed peat one-half to one foot in thickness, which are highly charged with lime and which rest upon shell marl of excellent quality. In the lakes the dominating plant is the stonewort (*Chara sp.*); the vegetation along the borders consists principally of sedges and rushes which pass rapidly into a bog heath and a pasture association. The shrubby cinquefoil (*Potentilla fruticosa*) predominates in places along the southern shore of the first Sister Lake.

No analysis was made of the peat on account of its high marl content.

COLUMBIANA COUNTY

The northwestern portion of Columbiana County is all high land and forms a portion of the divide between the waters of the Ohio and those of Lake Erie. The surface is generally covered with drift, but the coating is thin and the material in many places is coarse. The soil of the other portions of the county is for the most part formed by the disintegration of sandstone, limestone, and shales. The drainage has given great variety to the surface of the county, and hence the deposits of peat are not of exceptional extent, depth or purity.

BUTLER TOWNSHIP

Damascus Swamp.—This deposit is two miles east of Damascus in sections 3 and 4. The area, approximately 50 acres or more, and the location are indicated on the Lisbon topographic sheet of the United States Geological Survey. The peat which is in a shallow basin is fibrous and partially humified, but in most places scarcely more than 6 inches in thickness. The vegetation consists of wool grass (*Scirpus cyperinus*), several species of rushes (*Juncus sp.*) and sedges (*Carex sp.*). The samples were not analyzed.

In sections 33 and 34 is a peaty tract of about 100 acres in which the Mahoning River rises. The peat contains sandy layers probably due to seasons of flood.

CENTER TOWNSHIP

Guilford Bog.—This deposit is one-half mile east of Guilford in sections 7 and 8 of Center Township. It is a fairly large deposit of more than 200 acres with well decomposed peat averaging in places 6 feet. The area and location are shown on the Lisbon sheet of the United States Geological Survey.

An analysis of the sample taken from different layers and locations has been made by the writer in the laboratory of the Ohio State University. Though not to be compared with those of the United States fuel testing laboratory, it is of sufficient interest to be included here.

Analysis No. 24

	Air-dried.	Moisture-free.
Moisture	10.96	-------
Volatile matter	47.01	50.25
Fixed carbon	21.00	23.75
Ash	22.12	25.90
Nitrogen	1.98	2.42
Sulphur	0.71	0.80

The Calorific value is approximately 7520. B. t. u.

Along the eastern end the peat is woody. Lack of time made it impossible to put down holes for further samples, or to note the character of its vegetation. In places tamarack was observed; much of the area is tenanted by cattails; and about 40 acres of it are under cultivation.

A small deposit of about 80 acres in Salem Township, section 3, along Beaver Creek, proved too sandy for further anaylsis.

CRAWFORD COUNTY

Crawford County lies on the summit of the great watershed. The general flatness is relieved by broad surface swells or ridges often bordered on both sides by low peaty basins; almost all of these are now under cultivation.

AUBURN TOWNSHIP

From three to five hundred acres of peat land lie in the northern tier of sections of Auburn Township. It is part of a tract comprising several thousand acres in Huron County (p. 80). In early years this area was an extensive cranberry marsh, very wet and unproductive, except for the berries which grew there in great abundance. A much larger part of it was then covered with peat. Within the memory of the older residents the portion of the "New Haven Marsh" in this county extended over 3,000 acres more than at present. The tract in this township is today among the most productive in the county. Where well drained, cultivation and tillage have reduced the originally fibrous and matted deposit to a dark brown peat, well decomposed and partially humified. The thickness in places is between 4 and 6 feet; over the greater portion of the area the peat has unfortunately been burned, exposing a clay subsoil.

A composite sample of peat, taken near section 5, just across the boundary line of Crawford and Huron counties, gives the following analysis:

Analysis No. 64

		Air-dried.	Moisture-free.
Moisture		9.24	....
Volatile matter		49.81	54.87
Fixed carbon		23.24	25.62
Ash		17.71	19.51
Nitrogen		2.45	2.70
Sulphur		0.82	0.90
Calorific value	Calories	3756.00	4138.00
	B. t. u.	6761.00	7448.00

The fact that the surface of the bog has been burned over repeatedly probably accounts for the high ash content.

CRANBERRY TOWNSHIP

New Washington Bog.—Two miles south of New Washington is a peat deposit which originally was the largest cranberry marsh in the county and is said to have comprised over 2,000 acres. Prior to about 1881 the marsh extended over a considerable area in Chatfield Township. In the early years prior to 1820 "Cranberry Marsh" was known far and near by trappers and hunters as the retreat of wild animals. Large portions of the bog had plants of the shrub type with willow, red maple, poison sumach, alder, sphagnum mosses, cranberries, shield fern and others. Sycamore Creek, a winding branch of the Sandusky River, has its source in this marsh. During wet seasons the water in many places was quite deep, but now the level has been lowered by ditches and tiling.

With the exception of about 300 acres in sections 24, 25 and 26 the bog is now largely under cultivation. The greater part of the peat area has been burned off to a depth of 5 feet. A number of borings were so distributed as to test the southern half of section 25 and the eastern portion of 26. The peat has a thickness varying between 4 and 6 feet. It is coarsely fibered, light brown and is formed principally of bog meadow plants. Part of the surface is covered with an association consisting mainly of chokeberries, black alder and other shrubs. The peat underneath is of a better quality, that is, less fibrous, darker in color, firm and often well decomposed, but the lower portions are frequently fluid. Analysis No. 89 represents the composition of a mixed peat sample from section 26, on and adjoining the farm of A. F. High.

Analysis No. 89

		Air-dried.	Moisture-free.
Moisture		13.53	-------
Volatile matter		54.06	62.52
Fixed carbon		23.39	27.05
Ash		9.02	10.43
Nitrogen		2.79	3.23
Sulphur		0.41	0.47
Calorific value	Calories	4171.00	4824.00
	B. t. u	7508.00	8683.00

HOLMES TOWNSHIP

Burnt Swamp.—This is an area of about 50 acres in the western part of Holmes Township which is now well drained and under cultivation. When the first settlers came, this bog was thickly covered with poison sumach, alders, and willows, growing upon a peat bed about 3 feet in thickness. Fires have been repeatedly lighted by the Indians and settlers to dislodge the game. The deposit is well humified and contains a high per cent. of mineral matter. No analysis was made of the samples.

SANDUSKY TOWNSHIP

Bear Marsh.—The survey of 1838 indicates an extensive peaty tract of land of about 300 acres in section 1, Sandusky Township, about 3 miles southwest of Tiro. Since all of it is today under cultivation and has been repeatedly burned over, no further tests were made.

The early surveys of the county indicate extensive swamps in sections 1, 2, 11 and 20 of Liberty Township, and in section 17 of Vernon. Many were cranberry marshes and impenetrable thickets. Extensive drainage and cultivation have transformed these to humified soils which are now very shallow.

CUYAHOGA COUNTY

The wide area of drift clays which form the superficial material in many of the southern townships has yielded but little marshy or bog land. Near the lake the soil is sandy and derived from three ancient beaches which mark the position of the lake shore when the water level was from 100 to 200 feet higher than at present. The sandy belt between the ridges exhibits in places a black humus soil. This represents former shallow water basins which filled with vegetation, but rapidly underwent decomposition as cultivation increased. Of the more elevated localities only one, Solon Township, on the east of the Cuyahoga valley, has been found to contain a peat deposit.

SOLON TOWNSHIP

Solon Bog.—The deposit is in the extreme southwestern corner of the township near Geauga Lake station on the Erie Railroad. The location and area of 300 or 400 acres are shown on the Chagrin Falls topographic sheet of the United States Geological Survey. The deposit extends south into Summit County for a distance of about two miles, and over into Geauga and Portage counties on the east (Fig. 2).

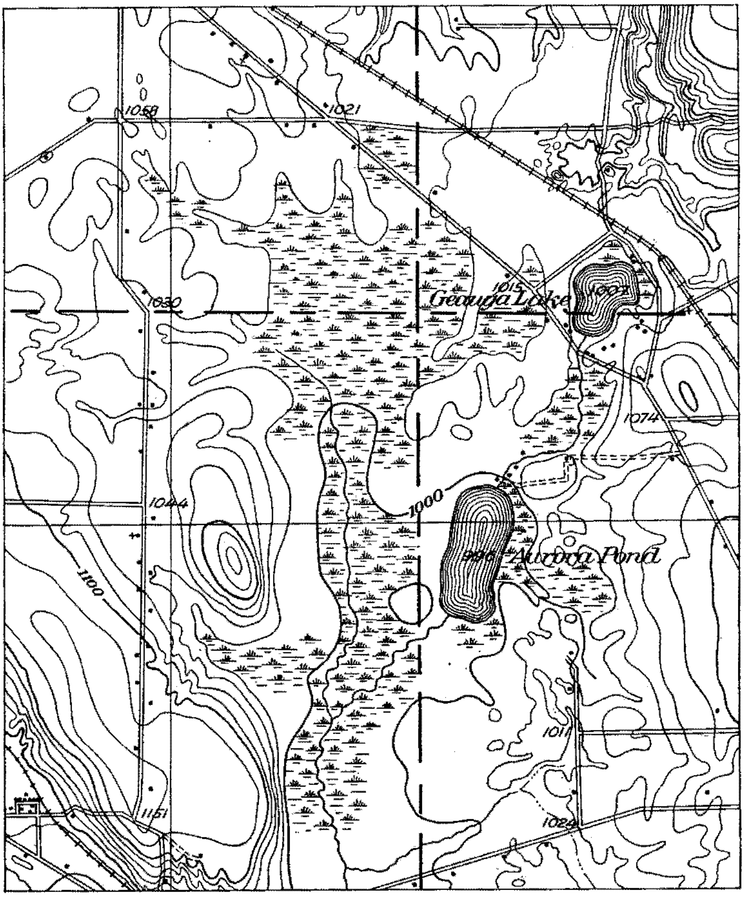


Fig. 2.—Map showing peat deposits at the intersection of Cuyahoga, Geauga, Portage and Summit counties and at Aurora and Geauga lakes.
Scale, 1 inch = 1 mile (2.5 cm. = 1.6 km.)

Borings made in all four counties are sufficient to show that in many places the thickness of the deposit is considerable, averaging 8 eet. The more easterly portion of the bog is probably in large part shallow. The deeper portions indicate at the first foot level a well decomposed blackish, but charred peat, but at a depth of 3 feet the material is slightly fibrous with woody fragments, while the sample near the 4-foot level shows roots and occasionally logs intermingled with the peat. At the 5-foot level the material is brown, slightly woody and almost non-fibrous. The quality of the peat increases toward the bottom of the deposit; at the 7-foot level it is dark brown and well decomposed, and at the 9-foot level a greenish brown peat is encountered, fine-grained in texture and formed largely from aquatic plants. At the depth of 11 feet the peat is clayey.

The surface of the bog is free from trees, the vegetation consisting mainly of sedges and grasses. Among the plants tenanting the area were noted wool grass (*Scirpus cyperinus*), a stiff sedge (*Carex vulpinoidea*), species of rush (*Juncus sp.*), arrow-leaved tear thumb (*Polygonum sagittatum*), bur reed (*Sparganium eurycarpum*), cleavers (*Galium sp.*), vervain (*Verbena hastata*) and sphagnum mosses. The sample to be transmitted for analysis was lost in transit, but inasmuch as the peat appears to be continuous with that of Geauga Lake a short distance to the east, and was formed possibly during the same time-interval, the analysis of the composite sample from that locality is given here:

Analysis No. 49

		Air-dried.	Moisture-free.
Moisture		9.01	-------
Volatile matter		46.45	51.05
Fixed carbon		21.39	23.51
Ash		23.15	25.44
Nitrogen		1.93	2.13
Sulphur		0.71	0.77
Calorific value	Calories	3795.00	4169.00
	B. t. u	6831.00	7504.00

The ash content of this sample is too high and the fuel value too moderate to make the deposit suitable for the manufacture of peat fuel. But the quality of the peat, however, in the middle portions of the bog is considerably better. Nevertheless the exploitation for fuel purposes should not be attempted until further tests and analyses have been made.

DARKE COUNTY

This county is situated upon the southern slope of the Ohio divide and formerly abounded in numerous small lakes and accumulations of vegetable material. Several peat deposits of considerable area exist in different portions of the county, but all are under cultivation today.

In the majority of townships the deposits in the main are small and it frequently happens that one and sometimes several gravel knolls or kames occur in the midst of a deposit. In accounting for them, Lindemuth in his report on the Geology of Darke County[1] attributes them to material of mud and gravel from melting icebergs, which was sorted and shaped by eddies, currents, and streams from melting glaciers.

[1]Lindemuth, A. C., Geol. Surv. of Ohio, Vol. III, 1878, p. 506.

BUTLER TOWNSHIP

Mud Creek Bog.—The deposit, which was formerly a shallow lake extending from its source in Harrison Township near New Madison to Greenville, a distance of about 10 miles, is indicated on the West Manchester topographic sheet of the United States Geological Survey. The portions examined and tested are near New Madison in Butler Township, sections 7 and 18, and in Harrison Township, section 13. In the former the peat is black, granular, slightly fibrous and well humified, and rests on clay. The area has been burned over, hence the peat is very shallow in many places and seldom has a thickness greater than two feet. Analysis No. 88 is that of a composite sample from the farm of C. McMiller and indicates clearly that the best use of the deposit is for local agricultural purposes.

Analysis No. 88

		Air-dried.	Moisture-free.
Moisture		12.72	-------
Volatile matter		37.91	43.44
Fixed carbon		10.03	11.48
Ash		39.34	45.08
Nitrogen		2.00	2.30
Sulphur		0.30	0.35
Calorific value	Calories	2248.00	2576.00
	B. t. u	4046.00	4637.00

HARRISON TOWNSHIP

The deposit just west of New Madison in Harrison Township, and that north of the town on the road to the Lakeview School, have a better quality of peat. The thickness averages 3 feet and in places 4. Fires have destroyed much of it. In texture the peat is somewhat fibrous and the upper layers are well humified and granular. Analysis No. 87 represents a composite sample of peat from the farm of F. Schlentz.

Analysis No. 87

		Air-dried.	Moisture-free.
Moisture		16.24	-------
Volatile matter		45.86	54.75
Fixed carbon		16.34	19.51
Ash		21.56	25.74
Nitrogen		2.55	3.05
Sulphur		0.53	0.64
Calorific value	Calories	3163.00	3776.00
	B. t. u	5693.00	6797.00

The nitrogen content in this sample is large, but that of ash is sufficient to injure the value of the peat as fuel.

The deposit is favorably situated on the Pennsylvania Railroad. It appears to be of good quality and perhaps amply sufficient for local needs, but the purity of the peat is not such as to render the deposit commercially important.

Along the railroad, numerous other places might be cited where peat occurs, but the indications are that the deposits are all of the same character as the two cited above. Near Weaver's Station in Neave Township and at Bridge Creek, approximately one and one-half miles southeast of Greenville, about two feet of well decomposed peat rest on the native Niagara limestone. The areas are not sufficiently extensive and in places the material contains too much mineral matter for commercial purposes.

Portions of the remains of a mastodon and of a mammoth are said to have been found in the peat deposits of Mudcreek Prairie. Local histories report that parts of fifteen or twenty skeletons of these great animals have been exhumed in various parts of the county.

The peaty areas in Brown Township, sections 9 and 17, cover an area of about 200 acres; Jackson Township has about 100 acres in section 26; in Washington Township the deposit in sections 23 and 24 has an area of about 50 acres. The peat is relatively impure and was not tested for analyses and fuel value.

DEFIANCE COUNTY

Almost the whole of the county, which belongs more properly to the Black Swamp district, exhibits a nearly flat and but slightly varied surface, rich in humus, that rests upon bowlder clay. Milford Township, in the northwestern corner of the county, is the only portion which is rolling and contains peat deposits.

The county had orginally much waste, marshy land and peaty soil. The land survey of 1818 shows that at that time tamarack bogs with red maple and black ash occupied almost the entire central portion of Mark and Farmer townships. The thickness of peat varied between one and three feet and lay on a level clay surface. The northwest corner of Farmer Township, sections 4, 5, and 6, had tamarack bogs quite recently. Artificial drainage, fire and cultivation have reduced the area of peat very considerably. A number of the deposits are traversed by streams and subject to occasional flooding and accession of silt. As might be expected the percentage of ash is high, the thermal value less than moderate, and the peat not of quality to justify the manufacture of fuel or of other products.

The great prairie, in section 16 of Adams Township, was formerly a shallow lake surrounded by extensive marshy land and was made by beavers cutting timber and damming the outlets. The county ditch has drained the area, all of which is now well humified and under cultivation. Elk horns and skeletons of various animals were found during the excavation of the ditch.

Washington Township had, in sections 10, 14 and 15, an extensive but shallow cranberry marsh, all of which is now well drained and being farmed.

In Hicksville Township the southern and eastern portions have well drained peaty tracts, which have been under cultivation for some time. Platter Creek and Gordon Creek marshes are shallow tracts of well humified soil that lie partly in this township.

Ladd's Lake, about one-fourth of a mile south of Clarksville in Milford Township, is surrounded with a narrow border of peat, approximately 12 acres in area. The material is light brown and fibrous to the depth of 5 feet, but at lower levels it is slightly fibrous, granular and rather fluid. The bottom was not reached at a depth of 18 feet. The vegetation around the inner margin consists principally of cattails and aquatic plants; toward the outer border are bog shrubs and red maples.

Little Lake is about one and one-half miles southeast of Clarksville in section 10, on the outside of St. Mary's ridge, a beach of glacial Lake Erie. A zone of peat about 10 feet in width surrounds the lake. The vegetation tenanting the area is found in almost continuous concentric zones. White and yellow water lilies are succeeded by knotweeds, cattails and sedges, and these in turn are replaced by shrubs and trees.

The following plants were noted: Several bog rushes (*Juncus acuminatus, J. tenuis, J. effusus*), sedges (*Carex lurida*), spike rush (*Eleocharis obtusa*), manna grass (*Glyceria = Panicularia fluitans*), panic grass (*Panicum sphaerocarpon*), chokeberry (*Aronia nigra = Pyrus melanocarpa*), poison sumach (*Rhus vernix*), buttonbush (*Cephalanthus occidentalis*), meadow sweet (*Spiraea salicifolia*), willow (*Salix discolor, S. amygdaloides*), red maple, black ash, wild cherry and elm.

Leman's Lake is about one and one-half miles southeast of Clarksville at the corner of sections 2 and 11. The vegetation surrounding this lake is in part that of the preceding one, but the swamp loose-strife is here the important mat-former.

A forest association surrounds the lake, consisting of red maple, aspen, oak (*Quercus coccinea*), black ash, elm, tulip tree (*Liriodendron tulipifera*), a few isolated walnut trees (*Juglans nigra*) and hickories (*Hicoria minima = Carya cordiformis*).

This association leads on the northwest side of the lake into a tamarack bog. The water table of the lake has been lowered 5 feet within recent years and as a result the tamaracks are rapidly dying out. They will be replaced ultimately by an association of deciduous trees such as that mentioned above. Sphagnum and polytrichum mosses are a frequent ground cover. Ferns such as the royal and the cinnamon are numerous and of luxuriant growth; tulip tree seedlings indicate the coming vegetation aspect. The high-bush blueberry (*Vaccinium corymbosum*), winterberry (*Ilex verticillata*), the swamp honeysuckle (*Azalea = Rhododendron viscosum*) and several other bog shrubs determine more specifically the physiognomy of the secondary layer.

The total area of the peat deposit about Leman's Lake is possibly 100 acres, but the exact limits could not be obtained. The peat is more or less uniform in quality in most places where tested; it is light brown in color, slightly fibrous, at times woody, and often somewhat fluid. Its thickness averages 14 feet. Over considerable areas around the outer margin of the bog, the peat is very shallow and heavily grown over with young aspen. The bog is not very advantageously situated as regards shipping facilities. The nearest point on the railroad, the New York Central line, is Edgerton, about 7 miles north.

The analysis of samples from the tamarack portion of this peat deposit is as follows (for the fertilizer constituents of this sample see table 32):

Analysis No. 82

	Air-dried.	Moisture-free.
Moisture	8.58	-------
Volatile matter	57.07	62.44
Fixed carbon	23.08	25.24
Ash	11.27	12.32
Nitrogen	2.34	2.58
Sulphur	0.47	0.52
Calorific value { Calories	4277.00	4678.00
Calorific value { B. t. u	7699.00	8420.00

A small peat deposit occurs east of the barn on the farm of F. Krill. The bog was originally a "cranberry marsh," but has been under cultivation for the past ten years. The peat is of almost the same character and texture as that just described. To the depth of 3 feet it is fibrous, compact, often matted and dark brown. At a depth of 5 feet water pockets are encountered with finely fibrous, brown material. Peat of this texture continues to the 11-foot level, where it becomes fibrous, light brown and firm. At the 13-foot level the peat is of the same texture. The bottom was not reached with the sampling instruments, the available length of which was 15 feet. The thickness of the deposit at the center, however, is more than that. Around the margin the peat is olive green, granular and only slightly fibrous. It rests on a blue clay; marl was not found. The total area of this bog is not over 5 acres. Analysis No. 83 represents a composite sample from this bog; its fertilizer value is indicated in table 32.

Analysis No. 83

	Air-dried.	Moisture-free.
Moisture	8.97	-------
Volatile matter	55.10	60.53
Fixed carbon	25.46	27.96
Ash	10.47	11.51
Nitrogen	2.63	2.90
Sulphur	0.34	0.36
Calorific value { Calories	4331.00	4759.00
Calorific value { B. t. u	7796.00	8566.00

A number of test borings were made on the east side of Leman's Lake. The samples were taken along a ditch which runs in an easterly direction on the farm of W. L. Wiles and receives the surplus water from the lake and from part of the bog under cultivation.

At a distance of 5 rods east from the inner margin of the lake, in the swamp loose-strife zone, the peat is fine-grained and dark brown to a depth of 9 feet. No bottom was reached with the available length of the sampling instrument. Twenty rods east of the border vegetation, in a portion of the bog covered with aspen and red maple, the peat is dark brown, slightly fibrous and very compact; the bottom was not reached. At 40 rods from the lake margin, in a clearing mostly covered with nettles, the peat is similar in character to that of the preceding sample, but at the 9-foot level the peat appears greenish, fibrous and often somewhat fluid. Another testboring was made at a point 50 rods from the lake border in an area under cultivation. Little difference was observed in the texture of the peat, and at a depth of 14 feet blue clay was found. No analyses were made of the peat samples.

HIGHLAND TOWNSHIP

Cranberry Marsh.—This bog is in section 15, one-half mile southeast of Ayersville. Its form and location are shown on the Defiance topographic sheet of the United States Geological Survey. The bog, which is partly encircled on the north, east and south sides by a sandy ridge, was until recently a cranberry marsh. It was partly burned over about 20 years ago, and though it has been under cultivation repeatedly it has never been productive and today is considered worthless. The area is probably 25 acres, and the average thickness of peat one and one-half feet. The samples taken from a variety of locations show a slightly fibrous, dark brown peat, decomposed but poorly humified. Its analysis indicates a high per cent. of ash, most of which is sand. The underlying subsoil is a compact sand.

On the portions of the bog which have been severely burned over, dwarfed plants of the following species were noted: Sedges (*Carex virescens*), bur marigold (*Bidens discoidea*), field sorrel (*Rumex acetosella*), knotweed (*Polygonum pennsylvanicum*), ragweed (*Ambrosia trifida*), pokeweed (*Phytolacca decandra*).

Toward the southeast, small trees of willow, aspen and poplar (*Salix petiolaris, Populus tremuloides, P. heterophylla*), with an occasional black gum (*Nyssa sylvatica*) and several bog shrubs, like chokeberry (*Aronia nigra = Pyrus melanocarpa*) and others, begin to appear. They are encroaching rapidly on the abandoned clearing and gradually become larger and denser as the uncultivated, wooded portion of the bog is approached. In the more open places near the burned area, the association includes polytrichum mosses more or less abundant as a ground cover, several sedges (*Carex virescens, C. canescens, C. scoparia*), bog rush (*Juncus effusus*), grasses (*Panicum huachucae, P. sp.*), spike rush (*Eleocharis obtusa*), cinquefoil (*Potentilla monspeliensis*), wild oat grass (*Danthonia sp.*), marsh St. John's-wort, (*Hypericum vir-*

ginicum), seed box (*Ludvigia alternifolia*), prostrate bramble (*Rubus hispidus*), meadow sweet (*Spiraea salicifolia*), wild rose (*Rosa carolina*), and several ferns (*Aspidium = Dryopteris thelypteris, Onoclea sensibilis*).

The slightly elevated sandy ridge, which borders the bog on the south, is wooded and contains among others red maple, yellow poplar (*Liriodendron tulipifera*), large toothed poplar (*Populus grandidentata*), sassafras (*Sassafras variifolium*), several oaks (*Quercus velutina*), witch hazel (*Hamamelis virginiana*), chokeberry (*Aronia nigra*), black alder (*Ilex verticillata*), black huckleberry (*Gaylussacia baccata*), prostrate bramble (*Rubus hispidus*), sedges (*Carex virescens*), and shield fern (*Aspidium = Dryopteris thelypteris*), indeed a peculiar mixture of southern and northern plants on a habitat of this character. In low and wet depressions sphagnum mosses and the dwarf bramble (*Rubus triflorus*) abounded.

Another and larger bog, considerably more advanced in development, lies south of the ridge, and is continuous with the one just described. The peat, which nowhere is more than 3 feet in thickness, is of the same texture and character, but more moist. This tract of land is considered worthless. The peat samples from this locality were not analyzed.

The central portion of the bog is open and covered with sedges and grasses. The vegetation around the bog meadow is arranged concentrically. A zone of wild rose (*Rosa carolina*) and spiræa (*Spiræa salicifolia*), with *Sphagnum* hummocks, is surrounded by the high-bush blueberry (*Vaccinium corymbosum*), black alder (*Ilex verticillata*) and chokeberry (*Aronia nigra = Pyrus melanocarpa*). This association leads into a willow, aspen and red maple zone. The outer border of the bog, along the sandy ridge, supports a woodlot vegetation.

ERIE COUNTY

Erie County has a surface that is quite flat and but little elevated above Lake Erie. With the exception of the valleys excavated in the drift, the ridges of glacial Lake Erie, which traverse the county from east to west, constitute the only diversity of topography. The slope is very gradual toward the lake, and along its shore in Margaretta, Portland and Huron townships, between the bar sections and the mainland, are at least 4,000 acres of marsh. The location and area are shown on the Bellevue, Sandusky and Vermilion topographic sheets of the United States Geological Survey. The accumulation of plant remains has been continuous over a long period of time. The vegetation consists principally of bulrushes (*Scirpus validus, S. americanus*), reed grasses (*Phragmites communis*), cattail, bur weed, arrow head and others.

The mass of the accumulation is loose, but homogeneous in texture. In most instances it seems to consist of a mixture from many places. Fragments of wood are not uncommon. The debris contains a high per cent. of mineral matter, principally fine sand and clay. By the aid of cribwork, jetties or piers much of this marsh could be reclaimed. Similar tracts have been brought into an arable condition without much difficulty in other states. No samples of peat were taken for analysis.

MARGARETTA TOWNSHIP

Castalia Prairie.—A marshy prairie of about 3,500 acres extends from Castalia to the west and north. There are moderately elevated hills to the south of the prairie, but the northern portions slope gradually toward Sandusky Bay. The peat over the greater part of the prairie is very shallow. Fires have swept over large areas. On a few small portions the peat is deeper.

The most common and characteristic plants prior to the drainage of the prairie were the reed (*Phragmites communis*), hoop-pole (*Spartina cynosuroides*), and blue joint. At present these plants occur only at a few isolated localities on deeper peat north and west of the Portland cement works. There are relatively large areas of a peaty marl upon which a heath association, consisting principally of shrubby cinquefoil (*Potentilla fruticosa*), with an occasional fringed gentian (*Gentiana crinita*), a small white lady's slipper (*Cypripedium candidum*?), and several grasses, is the characteristic cover. The stonewort (*Chara sp.*) is very abundant in the shallow pools formed by surface erosion. The association resembles the heath bog near Urbana in Champaign County, which has a similar substratum, but is of a greater depth.

The northwestern portion of the prairie has been artificially drained. The water from subterranean springs formerly flowed through the prairie. Of these the best known is the "Blue Hole," an orifice in the native limestone. The spring is a short distance east of Castalia, along the Sandusky division of the Cleveland, Cincinnati, Chicago and St. Louis Railroad. It maintains a nearly constant temperature and volume of water throughout all seasons, except during severe and protracted drought. The water is clear and cold, and being charged with lime incrusts all objects, as grasses, sedges and logs, with which it comes in contact. The spring is carpeted with masses and festoons of algae to a depth of more than thirty feet. The water contains much carbonate of lime and has given rise to extensive marl deposits which are now used on a large scale for Portland cement. The deposit of this material covers an area of several square miles.

The prairie, like many other areas situated along Lake Erie, has undergone a great many changes. Of these the most interesting and important is the one due to tilting and subsidence.

Testborings were made at a point about one mile west of the Portland cement factory, and indicate the following cross section. At a depth varying from one to two feet below the marly surface occurs a layer of peat ten inches in thickness. Below this is a fine-grained, cream-colored marl consisting principally, it seems, of *Chara* nodules. The thickness of the bed is 4 feet. It is underlaid by four inches of coarser stonewort intermingled with pebbles of calcareous tufa, a layer of which, about one foot in thickness, lies immediately below. Incrustations of rhizomes of the reed grass (*Phragmites communis*) and of other plants are more or less abundantly scattered throughout the coarser stonewort material. Beneath the tufa lies a second layer of peat two feet in depth, which is black, well decomposed, and slightly fibrous. Fragments of root-stocks, of reed grass and of wood are frequently found. Trunks of willow and red cedar have been removed in several places by the dredge on the land of the Portland Cement Company. The peat contains toward the bottom a mixture of shell marl. Below the peat is found another layer of *Chara* marl, one and one-half feet thick, intermingled with pebbles of calcareous tufa. The marl rests upon a third layer of peat, somewhat marly but apparently of the same texture and character as that of the second layer. The deposit in turn is underlaid with a marly blue clay.

This record provides additional evidence in support of the statement made by geologists that the country about the western portion of Lake Erie was once dry land at least 200 feet above the present lake level. The submerged marl beds and peat deposits, the caves upon the islands of the lake (Point Pelee, Kelley's Island, Put-in-Bay Island and several others), the inequalities in the height of old beaches on the mainland near Lake Erie, and along the other great lakes, indicate that the whole region has undergone subsidence. The comparison of the heights of benchmarks above the normal lake level shows that tilting is still going on, raising the water level on the entire southwestern border of the basin, converting into marsh extensive areas which were dry prairie. The rate of the deepening of the water has been studied by Moseley,[1] who investigated the age of the parallel ridges on Cedar Point and from the vegetation upon them obtained evidence that the water in Lake Erie has risen a little over two feet per century.

The formation of the peat deposit is unquestionably due to submergence, just as that of the marshes along the shore. Twice during the progress of each submergence, shore materials, the pebbles derived from tufa beds that formerly existed where the bay now is, spread over the surface covered by the advance of the lake. This deposit was followed first by mixed mechanical and organic material, then by almost pure *Chara* marl and finally by accumulations of vegetable matter. This indicates possibly a retreating, shallowing lake or else the formation of sand bars near its shore, which later acted as barriers to the northward drainage. After the filling and complete closing of the marsh by the growth and partial decay of plants there followed a lower water table, firmer surface conditions and favorable soil. Reed grasses and other plants occupied the area. Drainage and the nature of soil processes were then as now the factors which determined the order of succession of the series of plants leading to a natural meadow or to tree encroachments. These plants do not grow well now where it is wet, and hence point to a return of land conditions during which no deposition was made on

[1]Mosely, E. L., Formation of Sandusky Bay and Cedar Point; Proc. Ohio Acad. Sci., Vol. IV, 1904, pp. 179-238.

the surface. But the submergence of the west end of the Erie basin continued and again caused the lake to extend southward, and it may reasonably be expected that the waters will continue to spread over the adjacent lowland, in a manner similar to that of past centuries.

FAIRFIELD COUNTY

The northern part of the county has a relatively flat surface with occasional saucer-shaped depressions a few acres in extent, which hold water only long enough to form shallow accumulations of vegetable remains. Neither the quantity nor the quality of the material would warrant commercial development, for it is usually a black mucky peat with considerable mineral matter

Farther south the topography is hilly, and hence offers no conditions for peat formation. Only the territory lying upon the western slope of the divide between the Hocking and Scioto rivers shows any indication of having peat deposits.

AMANDA TOWNSHIP

The position of the peat deposit is shown on the Lancaster topographic sheet of the United States Geological Survey but is not indicated as bog land, for all of it is under cultivation. The area examined is in section 26 on the farm of J. A. Madden.

A number of testborings were made, which show that a large part of the deposit is underlaid by several sandy knolls. At a point one-fourth of a mile northwest of his residence one of these knolls was encountered. The peat at the 3-foot level is grayish black, somewhat fibrous, with roots and rhizomes of reed grass (*Phragmites communis*); it has the same color at the 5-foot level but is less fibrous. Near the 7-foot level the material is reddish brown, woody and more or less fluid. At the 9-foot level begins an admixture of sand, and below this was found quicksand with a sandy shell marl resting on gravel.

A line of holes due west from this elevation shows peat of a texture similar to that just mentioned, except that the woody layer occurs at the 9-foot level. At a depth of 11 feet the peat is fairly well decomposed, only slightly fibrous and somewhat woody Near the 13-foot level is material with a greenish layer formed principally from aquatic plants, sedges and grasses. A thin layer of shell marl on sand lies below.

In several places the presence of pyrite (?) and of gas was noticed which seemed confined near the 5-foot level. The peat from that level has a sulphurous odor. Considerable suction was encountered at some of the holes when the peat samples were withdrawn.

The deposit apparently represents an extensive, ponded area which was converted into a peat basin through the accumulation of aquatic plants, sedges and grasses which were later succeeded by willows and shrubs. At that stage of the development the area was flooded, possibly through the activity of beavers and probably on account of the growth of vegetation near a former outlet. Grasses and sedges began to encroach in greater numbers and gradually built up and thus filled the basin. The water level must have been considerably higher than at present, for the surface of the peat upon the knolls is at least 4 feet above the general level of the deposit.

Analysis No. 66 represents a composite peat sample from this locality.

Analysis No. 66

		Air-dried.	Moisture-free.
Moisture		7.58	-------
Volatile matter		53.35	57.72
Fixed carbon		19.42	21.02
Ash		19.65	21.25
Nitrogen		3.00	3.25
Sulphur		3.90	4.21
Calorific value	Calories	3904.00	4224.00
	B. t. u	7027.00	7603.00

The sample analyzed shows the peat high in ash and only moderate in thermal value, but the percentage of nitrogen is relatively higher than that of many other samples from Ohio. The ash content forms the principal handicap to the commercial development of the deposit.

FULTON COUNTY

Prior to 1858 there were large areas of land within the county upon which marshes and bogs abounded. Deep drainage has since been resorted to for the reclamation of the beds of vegetable matter. The areas have been burned over in large part, and are mostly under cultivation. Save a few small tracts of peat land in the centrally located townships there is little that would be favorable for anything other than agricultural development Neither the quantity nor the quality of the peat is satisfactory.

CHESTERFIELD TOWNSHIP

A large part of the surface consists of a succession of knolls, dunes and short ridges. Between them are numerous marshy tracts and peaty soils, all of which show considerable admixture of sand.

On the land of H. E. Borton, in section 28, is a tamarack bog which originally covered about 40 acres. The deposit is in a broad, shallow basin and is surrounded by low sand hills. With the exception of one acre on which the marketable tamarack had been cut out quite recently, most of the deposit is used as pasture. The peat has been burned in places. The deposit was sampled at various points, but nowhere was found a thickness greater than 2½ feet. The peat is dark-brown in color, well decomposed, with sandy layers resting on a hard clay. Even the best samples were more than half mineral matter, and hence were not transmitted for further analysis. Marl was not found, but it is said to occur in similar deposits in the neighborhood.

DOVER TOWNSHIP

A large number of the depressions among the sand dunes contain peat. The thickness varies between six inches and two feet. The material in some places is moderately coarse, not much decomposed and contains many living roots of the herbs and grasses tenanting the habitat. No analysis was made of the samples.

ROYALTON TOWNSHIP

In this township the redeemed swamp, marsh and bog land is said to be more fertile now than the higher land. An exception to this is a tract of peaty soil of about 100 acres in sections 28 and 29, which was originally a cranberry marsh. The area has been drained and burned over and has been repeatedly cultivated with but poor success. The deposit is shallow but there are occasional pockets of greater thickness, though the location of these has not been determined.

Much of the peat is charred, only moderately fibrous and the proportion of mineral matter rather high. The underlying material is sand and in places clay. These constitute the principal drawbacks to its commercial development. It is possible that over certain small areas the thickness of the peat is greater and the texture and quality better. No analyses were made of the sample.

GEAUGA COUNTY

The characteristic physical feature of the county is the elevated table land, a conglomerate or pebbly sandstone, whose limits define almost exactly the western, northern, and eastern boundary of the county. The central part is a nearly level surface that was smoothed by ice action. The elevated position of the county with its rounded hills and the peculiarities of the soil, a tenacious clay resulting from the disintegration of clay shales mingled with the drift, would seem to promise a supply of peat sufficient at least for local purposes. In the northeastern portions of the county, particularly in Mon ville Township, there are several small shallow bogs with a clay bottom, in one of which was found in 1870 the skeleton of a young mastodon. In only two townships of the county is there an indication of an important amount of peat. There are several small lakes which have peat in them. They afford the most interesting examples in the State of the partial filling by the growth and decay of vegetation, and the character of the plant associations succeeding each other during the filling process. At the extreme southwestern corner of the county is a deposit wh'ch represents a completely filled water basin. This was at one time a large lake which was gradually filled with an accumulation of vegetable matter and thus converted into a peat deposit. The plants, which are now growing upon the surface of the peat in the partially filled lakes described below, undoubtedly formed the peat of the deposits in question.

BAINBRIDGE TOWNSHIP

Solon Bog.—West of Geauga Lake in the extreme southwest corner of the township there are, approximately, 70 acres of peat land. The location and the area are shown on the Chagrin Falls topographic sheet of the United States Geological Survey (Fig. 2). The deposit extends west into Cuyahoga County, southwest into Portage, and south into Summit for a distance of about two miles.

The testborings were so distributed as to cover portions in all four counties They show that in many places the thickness of the deposit averages 8 feet. In considerable areas around the margin, the peat is shallow and shows the effects of repeated fires. The middle part of the deposit could well be utilized for industrial purposes and the rest for agricultural uses. But before exploitation for fuel is attempted, further tests and analyses should be made.

The borings of the portion of the bog in this county indicate at the first foot level a well decomposed peat intermingled with charred, woody fragments. At the 3-foot level the peat is slightly fibrous and woody but stumps and roots were not found. The peat at the 5-foot level is of a better texture, well decomposed and rather firm but containing woody fragments. It is similar in character at the 7-foot level but more thoroughly decomposed. The deposit below the 9-foot level rests on a clay substratum. The samples taken for analysis were lost in transit.

The surface of the bog is free from trees, and the vegetation growing on the deposit is mainly a typical lowland pasture association that contains sedges and grasses.

Geauga Lake.—This body of water occupies a rather deep depression which is fed by underground springs. The shore on the east and west side has a border of peat the exact limits of which were not determined. The deposit probably nearly corresponds to the limits of the 1,020-foot contour line indicated on the Chagrin Falls topographic sheet, but the swamp symbol is not given on the map.

The major portion of the peat border is covered to the water's edge on the west side with bog shrubs and on the east with tamarack. The marginal succession comprises a submerged association consisting of the tape grass (*Valisneria spiralis*), pond weeds (*Potamogeton sp.*), and others; several members of the semi-aquatic and floating associations such as the water lilies, knotweeds, pickerel weed and several more.

The vegetation of the shore includes the swamp loose-strife association among which are crowded the shield fern, pickerel weed, arrow-head, marsh St. John's wort and sphagnum mosses. The peat at this point, about 5 feet to the west of the water's edge is light-brown, fluid, somewhat fibered but otherwise well decomposed to the depth of 14 feet. Below the 14-foot level the peat is greenish brown, almost laminated. At the depth of 15 feet a pond filling is encountered; that is, a fine-grained, rather compact vegetable detritus which spreads over the lake bottom filling it with a soft oozy mud. This is found at the 17-foot level and deeper; the bottom of the layer was not reached with the available length (19 feet) of the sampling instrument.

The swamp loose-strife association is closely followed by a bog shrub association; alders (*Alnus rugosa, A. incana*), and poison sumach with a ground cover of sphagnum mosses, sedges (*Carex sp.*), ferns (*Onoclea sensibilis*) and occasionally skunk cabbage. This zone is a narrow belt and leads into a bog shrub and bog forest association which on this side (the western shore) consists principally of the red maple. The shrubs underneath the trees are arrowwood, buttonbush and occasionally poison sumach; the lower layer is one of ferns (*Osmunda cinnamomea, Onoclea sensibilis*), sedges, marsh St. John's wort and huckleberry. This zone extends outward about 40 feet from the border of the lake. The peat at this point is brown and fibrous to a depth of 9 feet and is intermingled with woody fragments. At the 11-foot level it is very fluid and is woody at the 13-foot level, but appears a laminated, greenish brown to the 15-foot level. Below this lies an olive-green, fine-grained clayey peat. The bottom was not reached.

The bog forest association leads into a vegetation zone which comprises for its main species the swamp rose, elderberry, meadow sweet, several asters and willows. The peat underneath the vegetation cover is very sandy and varies in thickness from 3 to 5 feet.

The samples of peat from the testborings in the shrub zone give the following analysis.

Analysis No. 49

		Air-dried.	Moisture-free.
Moisture		9.01	-------
Volatile matter		46.45	51.05
Fixed carbon		21.39	23.51
Ash		23.15	25.44
Nitrogen		1.93	2.13
Sulphur		0.71	0.77
Calorific value	Calories	3795.00	4169.00
	B. t. u	6831.00	7504.00

From this analysis it appears that the ash content is high and the thermal value only moderate. This is attributed mainly to the fact that samples from the sandy layers and from near the bottom are included. The quality of the upper portions is undoubtedly better.

The peat would have to be excavated by dredging or by pumping. The Erie Railroad passes just a short distance north of the lake.

Part of the deposit on the eastern shore of the lake is covered to the water's edge with tamarack. Beneath them is a rather open growth of bog shrubs, chiefly those belonging to the heath plants. Of these the chokeberries, the high-bush blueberry and the mountain holly are most frequent and noticeable. With these heaths occur the alder, buttonbush and poison sumach nearer the water's edge; red maple and young elms are found farther inland. The ground cover consists in part of

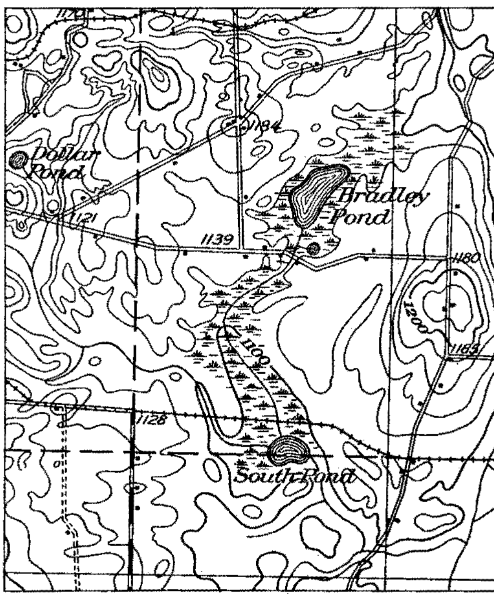


Fig. 3.—Map showing location and area of peat deposit about Bradley Pond (Kellmore Lake) and South Pond (Snow Pond) in Geauga County.
Scale, 1 inch = 1 mile (2.5 cm. = 1.6 km.).

sphagnum mosses, a frail growth of tall sedge (*Dulichium arundinaceum*), several ferns (*Aspidium* = *Dryopteris thelypteris, Osmunda cinnamomea, O. regalis*) and others.

The water level of the lake must have been lowered several years ago. The extent to which the peat deposit has settled is shown by the tamarack trees with exposed roots. The depth of the deposit was not determined.

BURTON TOWNSHIP

Bradley Pond (Kellmore Lake).—This most interesting of all the ponds visited in this county is located in the southeastern quarter of the township. It is about midway between the Burton branch and the Garrettsville branch of the Eastern Ohio Traction Company. The form and the area of the basin are shown on the Garrettsville topographic sheet of the United States Geological Survey (Fig. 3). The deposit of peat around the basin approximates 100 acres and the limits correspond very closely with the 1,120-foot contour line but the swamp symbol for these tracts is not indicated on the map. The major part of the lake and adjoining peat deposit is on the land of E. Moore and C. H. Kellso.

The lake as a whole represents a later stage than Geauga Lake of the process of filling a basin by vegetation. In many ways, even to the species of the plants concerned in the succession of plants it corresponds to types of peat bogs characteristic in northern Michigan. The only possible difference which could be noted consists in the greater luxuriance of southern shrubs in the wooded portion of the bog.

Vegetation of the submerged aquatic type is practically absent in the lake (Plate II). There are some aquatic mosses on small patches of bare peat just below the water surface. The bottom of the pond is apparently made up of dark colored peaty ooze. The yellow and white water lilies, pickerel weed and arrow-arum appear scattered and in places thickly crowded. The filling process in this basin is proceeding very slowly. The greater part of it seems to be done by the aquatic plants, for the associations of bog meadow and of bog heath plants which lead into the tamarack occur in rather narrow zones.

The lake is fringed by a zone of swamp loose-strife. The cattail occurs only rarely. The shore vegetation, above the surface of the water, is quite different in character and species in different parts of the pond. At the southern end a dense growth of sphagnum mosses and cranberry vines forms a well marked zone, several feet in width. The association has a varying distance from the edge of the swamp loose-strife border. Confined to this zone almost exclusively are several sedges (*Carex canescens*, *C. interior*), the buckbean, shield fern, tall sedge (*Dulichium sp.*) pitcher plant and others. The surface of the quaking mat is but little above the water's level. The testboring shows a coarsely fibrous peat to a depth of about nine feet. Below this level the peat is finer in texture and gradually assumes the character of a greenish brown, well decomposed filling. The depth beyond the 17-foot level was not determined.

Shoreward the cranberry-sphagnum association is closely followed by a narrow zone of low bog shrubs—the leather leaf and the bog rosemary with low blueberry (*Vaccinium vacillans*). Of these the former is more conspicuous in point of numbers and size. The absence of any extensive areas of sedge and heath points to relatively slow encroachment upon the open water by the plants, since shrubs do not spread as rapidly in the form of a mat as the sedges and some of the heaths such as cranberry, leather leaf and others. Yet the step-like advances which plant associations make over the surface of the water and the filled-in portions in a well-marked zonation are very distinct.

As the distance from the open water is increased, the bog heaths merge into a tall bog shrub association, the members of which are alders, poison sumach, chokeberries, winterberry, mountain holly, the high-bush blueberry, low blueberry, azalea, arrowwood, and occasionally small tamaracks. As an undergrowth are plants belonging to the bog meadow and the bog heath, but they are less common and in

PLATE II.

Tamarack Bog at Bradley Pond (Kellmore Lake) in Geauga County.

(Photograph by L. King.)

poor condition as though in an unfavorable situation. The surface of the peat is higher, firmer and less easily shaken.

Around the tall bog shrub association and extending nearly around the entire lake is a mature tree-covered zone. Tamarack, yellow birch, white pine and hemlock make up the growth. The tamaracks are in several places the taller and presumably the older trees. They generally overtop the other species and appear of greater age. A portion of the margin of this lake is shown in Plate II. Sphagnum mosses cover occasional spots in this conifer zone, but they are nowhere abundant. It is often pale in color and quite dry at the top as though dead. In moist depressions it seems to be growing better; areas several square feet in extent are frequent, covered with green and fresh sphagnum. Polytrichum mosses and club mosses (*Lycopodium lucidulum*) are often found as dense mats. Several orchids (*Habenaria clavellata, Cypripedium acaule*), are quite common with wintergreen (*Gaultheria procumbens*) and occasionally Indian pipe (*Monotropa uniflora*), gold thread (*Coptis trifolia*), and the long sedge (*Carex folliculata*). The ferns are the most abundant plants. The cinnamon fern especially makes a striking display with its large tufts of long and broad fronds. The shrubby species, most of which have been listed above constitute the greater part of the association under the shade of the trees.

Several borings were so distributed as to test the peat of the wooded zone. The notes which were taken agree in the main and show a well decomposed, somewhat woody, reddish brown peat near the surface, which becomes dark upon exposure to the air. At the 5-foot level the peat is of a similar character but slightly more fibrous and very fluid. Below this occurs a coarsely fibrous variety. At the 7-foot level the material is again well decomposed but more or less woody. In a few places layers of sandy peat were noted near the 11-foot level, resting on a blue clay, but deeper pockets of the material are frequent in which a fine grained filling occurs at a depth of 17 feet.

Farther landward where the peat is drier, firmer, darker in color and well decomposed, a dense growth of red maple, black ash and elm occupies the area and extends practically around the lake. The trees are all of fairly large size. Associated with them are the wild cherry, beech, white oak, basswood, magnolia and juneberry with an undergrowth of spice bush, dogwood, swamp honeysuckle, high-bush blueberry and others of the bog shrub association. The fertilizer value of this sample is indicated in Table 32. The analysis of the peat samples from the portion of the bog covered with deciduous trees, is as follows:

Analysis No. 51

		Air-dried.	Moisture-free.
Moisture		10.11	------
Volatile matter		54.01	60.09
Fixed carbon		25.16	27.96
Ash		10.72	11.95
Nitrogen		2.00	2.24
Sulphur		0.26	0.29
Calorific value	Calories	4366.00	4856.00
	B. t. u	7859.00	8741.00

Everett Lake.—A smaller pond, Everett Lake, lies a short distance south of the one just described (Fig. 3), and is quite dissimilar in the plant associations which border it. In the open water are a few much scattered water lilies. The swamp loose-strife zone is narrow. A densely crowded tamarack growth surrounds the entire lake as a nearly concentric border. The younger trees form a successively lower vertical layer as the edge of the water is approached (Plate I). A very abrupt change is noticeable in the character of the vegetation usually found between the tamarack zone and the bog shrub, bog meadow and the shore associations immediately lakeward. This is due to the very small width of the respective zones. Under the shade of the tamarack are a few plants which have been given in the list above for Bradley pond.

There are no indications here of any recent advance lakeward of the marginal and shore successions. The trees are growing nearly to the water's edge and several are of good size and many years old. The exceedingly narrow zones of bog meadow and bog heath consist of plants which appear thrifty but do not seem to make much growth upon the open water.

TROY TOWNSHIP

South Pond (Snow Pond).—This body of water is small and is surrounded by a dense growth of bog shrubs. Its area and location are shown on the Garrettsville topographic sheet of the United States Geological Survey (Fig. 3). The northern shore of the lake has a deposit of peat of good quality. It extends in a deep narrow basin northward into Burton Township almost to the limits of the 1,100-foot contour line and is bordered by high hills. The area was not determined but probably approximates 200 acres. A number of borings were made and so distributed as to test various portions of the deposit. The greater depths are along the creek which traverses the pond in a direction from northwest to southeast, and on both sides of the track of the Eastern Ohio Traction Company which traverses the bog in an east and west direction.

At points near the lake the peat to a depth of 15 feet is brown and well decomposed, but at the 17-foot level the material is somewhat marly.

North of the electric railway the peat is of a similar texture to the depth of 17 feet. As the 1,000-foot contour line is approached, east, north and west of the deposit, the borings indicate a sandy peat resting on blue clay which in turn lies on the conglomerate.

The part of the bog south of the track is an open grassy meadow; while to the north the larger portion of the deposit is heavily wooded. Tamarack and white pine are fairly abundant and in good condition. In the character of the vegetation this bog is similar to that of the Pymatuning tamarack bog (p. 33), but in some respects it represents a more advanced stage. The undergrowth has a more southern aspect because of the preponderance of southern shrubs and herbs. Its physiognomy is similar to that of the Mantua bog (p. 110).

The peat samples from this locality were lost in transit. It is probable that the ash content will be found high because of the proximity of sandy ridges; the presence of the creek rendering this fact still more probable. Tests and analyses should be made, therefore, before the exploitation of the deposit for fuel purposes is attempted.

MUNSON TOWNSHIP

Quite different in the stages of development are the sand-plain lakes so numerous in Munson, Newbury, Claridon and other townships. Some of these unfilled lakes are shallow with scarcely a trace of peaty deposit, while others are partly filled. Only one of these, the pond at Fowler's Mills, is densely covered with aquatic plants like the white and yellow water lily, pickerel weed, arrow arum, hornwort, water weed and others. Several species from the shore succession grow in dense masses throughout the central area occupied by the water plants. Cattail alternates with the slender sedge (*Dulichium sp.*), swamp loose-strife and woolgrass. Among these appear, and apparently without relation to the nature of the substratum, sticktight, touch-me-not, cleavers, wire grass and milkweed (*Asclepias tuberosa*). Thickets of wild rose, alders and buttonbush fringe the pond shoreward. It is an unusually indiscriminate combination, and probably the result of recent disturbances in the water level. There is no indication that the bottom of this depression, shallow as it is, has ever been filled with peat.

Bass Lake, Punderson Lake and others show the more usual succession of plant associations. The percentage of ash is high in much of the peat. Sand and clay, derived from erosion during seasons of heavy rain, are the main impurities. The plants which advance over peat of this character and closely follow the swamp loose-strife zone are buttonbush, arrowwood, alders and willows. They form around the pond a thicket border from a few feet to a few yards wide and sometimes grow to the edge of the water. Back of these shrubs, shoreward, are the red maple, ash, elm, wild cherry, dogwood, and others.

Here more than anywhere else, perhaps, is the importance of the character of the peat in relation to succession of plant associations impressed upon the observer. Better physical conditions, especially in sanitation and biological processes within the soil are the efficient factors in the elimination of bog meadow and bog shrub association.

GREENE COUNTY

Aside from the valleys the general topographic features of the county are those of a plain. Deposits of drift, consisting of water-washed seams of sand and gravel intermingled with bowlder clay, have been left over much of the county. Most of the impervious clay has been changed into a porous, light and permeable layer of soil through the action of weathering, the incorporation of vegetable matter and the excavating action performed by earthworms, beetles, ants, crawfish and other animals. Even the poorest and most stubborn clay of the State can be made highly serviceable through this process. As in many other sections a negligent system of farming has reduced much of the upland soils to an unproductive, tenacious clay. Robbed of the amount of vegetable matter which they contained at the time they were covered with marshes and forests, their color is now whitish. While there is no lack of the mineral constituents needed for plant growth there is a shortage of humus. Doubling the amount of organic matter would increase more than two-fold the productivity of the so-called "worthless" clay soils. Experts are agreed that the want of fertility in most unproductive soils of whatever character must be ascribed to their physical condition.

There are a few flat-lying districts of greater or less extent in which the deposit of bowlder clay has given rise to an accumulation of peat several feet in thickness. Most of the deposits are small and occur scattered as isolated tracts throughout the county. In the southeastern part, in Jefferson, New Jasper, Silver Creek and Ross townships, there are areas considerably larger, which extend beyond into Fayette and Madison counties. But their proportion of organic matter—39 to 55 per cent.—though high, is not sufficient to class them among the profitable peat accumulations. They are occasionally upland prairies, but for the most part "bottom lands" and do not need an extended description. It may be possible that they contain a considerable amount of peat in isolated pockets. Most of the localities visited in these townships are some distance from any station and hence were not tested sufficiently to show the area and depth of the accumulation of vegetable matter.

BATH TOWNSHIP

An example of a better grade of peat is that in Bath Township, which may be taken as a good representative of a completely filled basin in the drainage valley of Mad River.

Simm's Bog.—This peat deposit is in section 1 and 2 near Simm's station, about 6 miles northeast of Dayton. It is favorably located along the Dayton and Springfield Electric Railway, the Big Four (Cleveland, Cincinnati, Chicago and St. Louis Ry.) and the Cincinnati line of the Erie Railroad. The Dayton topographic sheet of the United States Geological Survey shows its location, but the swamp symbol is not indicated on the map. The area is well drained and most of it is under cultivation or in use for pasture. The deposit includes many isolated knolls and scattered ridges which were formerly islands in the flat-lying tract of over a thousand acres.

Borings were made on the land owned by J. S. Delong, and were so distributed as to test portions of the peaty area. The surface layer is a structureless, nearly humified black peat and contains a large amount of shell marl. At a depth of two feet the peat is fibrous, grayish black, but soon takes on a reddish color as the deeper portions of the deposit are reached. Below the 3-foot level the peat is dark brown in color and well decomposed but not entirely free from fibers. At the 5-foot level the debris is of a lighter brown color, intermingled with woody fragments and with marl below. At a depth of 7 feet the peat is grayish brown, structureless, and formed of a mire or mud which is intermixed with shells and a sandy marl.

A composite sample of the peat from this locality gives the following analysis:

Analysis No. 85

		Air-dried.	Moisture-free.
Moisture		15.56	-------
Volatile matter		49.58	58.72
Fixed carbon		20.44	24.20
Ash		14.42	17.08
Nitrogen		3.04	3.60
Sulphur		1.62	1.92
Calorific value	Calories	3869.00	4582.00
	B. t. u.	6964.00	8248.00

The sample is moderately low in ash and of medium thermal value.

HANCOCK COUNTY

The county is in part somewhat undulating in its general surface features, but the larger portion is flat and little diversified. Several low ridges of stratified gravel and sand cross the county. The soil is a heavy clay. Depressions or water basins do not occur with a greater depth than a few feet. Before its settlement the county contained vast tracts of marsh, and extensive areas were under water for several months in spring and early summer. They were prairie-like areas, destitute of trees, with a vegetation cover consisting mostly of grasses and sedges. Between the ridges were low, marshy areas known locally as "swales;" artificial drainage has brought all of these under cultivation. Accumulations of peat are mostly shallow and contain a high per cent. of mineral matter. In Amanda Township, where occasional peaty tracts were thinly timbered, willow thickets predominated. The peat has been burned off. In section 7, of the northwestern quarter, is an impure peat, the area covering about 5 acres. Several strips of similar material are found between McComb and Deweyville in Pleasant Township.

BIG LICK TOWNSHIP

Big Spring Prairie.—A bog-like area comprises a number of sections in this township, and extends southeastward into Big Spring Township, Seneca County. It is part of a peat-covered basin containing be tween 1,500 and 2,000 acres. From the fact that within the memory of the older residents no trees were known on the soil, it is locally spoken of as the "prairie," and was formerly a famous cattle range. The location is shown on the Fostoria topographic sheet of the United States Geological Survey. No swamp symbol is given on the map but the exact limits of the peaty deposit in this township correspond nearly with the limits of the 800-foot contour. Whatever the cause or the nature of the depression, whether between two beaches of glacial Lake Erie or a drainage channel of the ice sheet, the prairie was undoubtedly a lake. Wave-formed ridges and beaches, small sand dunes such as the wind has produced in bays and along the shore of Lake Erie, quicksand, and similar evidences of glacial lakes exist in various portions of the prairie in this township and in sections 29 and 30 of the adjoining one (Big Spring Township in Seneca County).

Borings were made at various places on sections 33 and 34 at the junction of the Carey-Findlay road with the one north of Vanlue, and on sections 20, 21, 22, 27, and 28. The peat is well decomposed, nearly humified at the surface, only slightly fibrous below, and very compact throughout. It is nowhere more than 3 feet thick, and rests on a clay hardpan. Near the low dunes the peat is sandy.

No analysis was made of these samples, but the peat is in every respect like that of the deposit extending into Seneca County. The analysis here furnished is that of a composite sample from section 30 in Big Spring Township. It indicates a medium thermal value.

Analysis No. 38

		Air-dried.	Moisture-free.
Moisture		11.02	-------
Volatile matter		50.48	56.72
Fixed carbon		20.96	23.56
Ash		17.54	19.72
Nitrogen		3.09	3.48
Sulphur		1.48	1.67
Calorific value	Calories	3831.00	4305.00
	B. t. u	6895.00	7749.00

UNION TOWNSHIP

Cranberry Marsh.—This is a narrow strip of peaty soil of about 400 acres in sections 23 and 24 and which extends across the line into Orange Township. The area is partly under cultivation, covered in places with impenetrable alder and willow thickets, and now gives but little indication of having been a cranberry marsh. The vegetable accumulation is rapidly undergoing disintegration and oxidation. The debris, which is well humified, granular and contains a high percentage of mineral matter, is more correctly called a peaty clay loam. The area, in most places, has been almost constantly under the plow, but unless the organic matter exceeds that in the subsoil it is safe to say that its physical texture will alter and the color of the soil become whitish; it will revert to a tenacious, unproductive clay that can scarcely be called a soil. Processes precisely similar to these but only far more rapid in their action are going on in the soils of many uplands. They are the incipient stages of "exhaustion" and usually lead to the abandonment of the farm.

HARDIN COUNTY

This county is situated on the watershed between Lake Erie and the Ohio River. The surface of the northern part is flat with a clay soil; the southern portions have numerous gravel knolls upon a brown hard clay and the topography is gently undulating.

Three extensive marshes,—(1) the Scioto, (2) the Hog Creek and (3) the Cranberry—lie on the western half of the county (Fig. 4). Their aggregate area is about 25,000 acres or approximately 39 square miles. Formerly water covered them during the greater part of the year. The Scioto River enters the first of these marshes and until recently the channel of the stream is said to have become lost in it. In a similar manner Hog Creek drained the other marsh. "The frequent occurrence of such marshes," says Winchell in his report on the geology of the county,[1] "on the broad watershed between the Ohio River and Lake Erie, or near the sources of streams which flow in opposite directions from its summit, is a feature in the general physiography of northwestern Ohio which deserves special mention. There seems no doubt that they were once shallow lakes. The occurrence of shell marl below the peaty surface, and of sandy deposits about their margins, indicates not only that there was a time when they were receiving the annual freshet washings of calcareous matter from the adjacent drift surface, but were also agitated by the wind into little waves which broke upon a sandy beach. Other similar undrained places in the old drift surface, situated further down the slopes of the great watershed, were sooner filled by the greater accumulation of alluvium, or were drained by the more rapid excavation of their outlet by the increased volumes of the streams." By the lowering of the outlet and the construction of a system of tributary ditches the whole area has been brought under cultivation, and is now ranked among the best farming land in Ohio. Immense crops of onions, potatoes, corn, celery, cabbage, carrots, etc., are grown annually.

MARION TOWNSHIP

Scioto Marsh.—The area of the Scioto marsh is about 16,000 acres. More than one-half of it is within the boundaries of Marion Township, while the balance is located in Round Head, McDonald,

[1]Winchell, N. H., Geological Survey of Ohio, Vol. II, 1874, p. 353.

Lynn, and Cessna townships. Two natural ridges cross the county. The most southerly of these prevented the northward drainage of the Scioto marsh and deflected the Scioto River easterly across the county

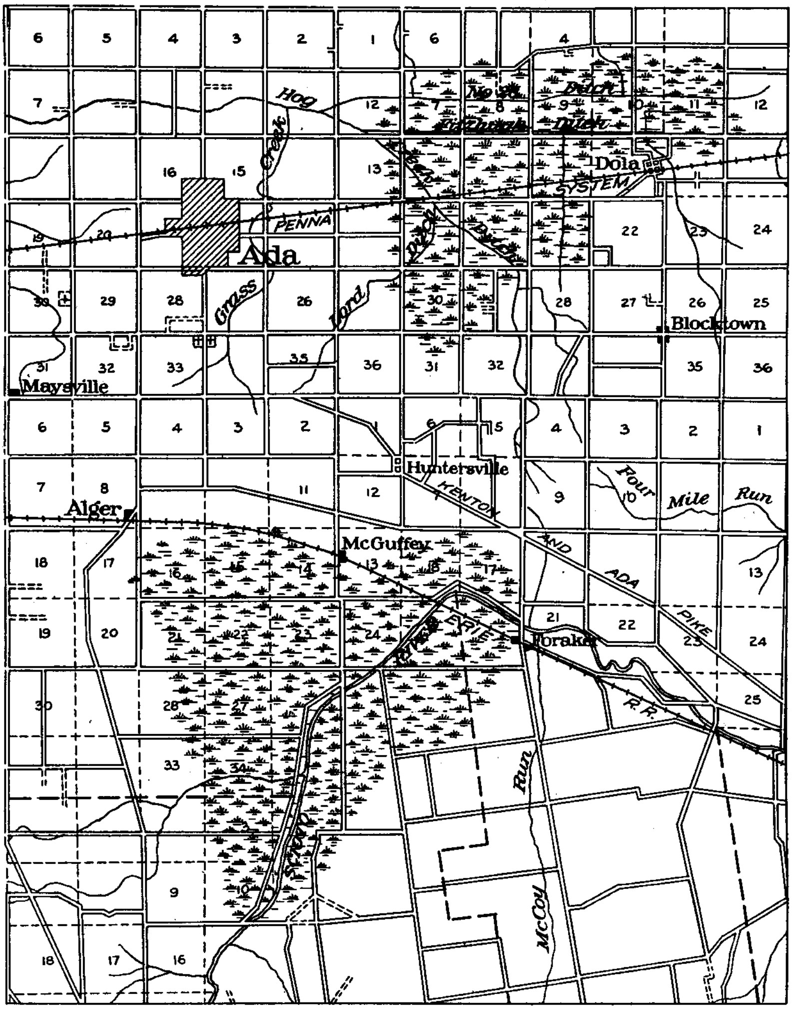


Fig. 4.—Map showing location and area of Scioto Marsh and Hog Creek Marsh, Hardin County.
Scale, 1 inch = 3 miles.

instead of permitting it to follow the natural slope. The marsh was a constant source of malarial disease to the early settlers until its artificial drainage, which was begun in 1859 and resumed in 1883. With the exception of a few acres, all of the marsh has been brought under cultivation.

The nearly level surface of the drift clay which forms the bottom of the former lake basin is covered with peat varying in thickness between two and ten feet.

A series of testborings was made at various places on the marsh. The peat near the surface is well decomposed and of a blackish brown color. At a depth of 3 feet the peaty soil is grayish brown, firm, somewhat fibrous, containing seeds, fragments of rhizomes of the reed grass and of several other grasses and sedges. Below this, at a depth of 5 feet, the peat is greenish gray, indicating a high silt and clay content, with quantities of fibrous plant remains and shell marl.

Analysis No. 61 represents a composite sample from an onion field on the land owned by W. H. Millikin, on section 27 of Marion Township, about 2½ miles south of McGuffy. The tract has been under cultivation 15 years; onions and corn being grown in alternation.

Analysis No. 61

		Air-dried.	Moisture-free.
Moisture		10.85	-------
Volatile matter		52.47	58.86
Fixed carbon		23.98	26.90
Ash		12.70	14.24
Nitrogen		3.00	3.37
Sulphur		1.09	1.22
Calorific value	Calories	3921.00	4398.00
	B. t. u	7058.00	7916.00

To indicate the "fertilizer" constituents of the soil, analyses quoted by Bonser[1] are given.

Analysis of Peat Soil from Scioto Marsh

Sample.	1	2	3	4	5
Nitrogen as Ammonia	1.09	0.95	0.90	1.40	1.44
Phosphoric acid (P_2O_5)	0.09	0.13	0.09	0.07	0.10
Potash (K_2O)	0.10	----	0.10	----	0.15

Less than a quarter of a mile northeast of the farmhouse is a wood lot, the vegetation cover of which consists mainly of red maple, several willows, buttonbush, elderberry, red osier dogwood, and weeds such as the ragweed (*Ambrosia trifida*) and horseweed (*Erigeron* = *Leptilon canadensis*), the latter more than 12 feet high. The area shows the effects of frequent fires. It is said that the filling of the entire basin was seriously retarded by the Indians who annually burned the grasses and sedges for the purpose of driving deer and other wild animals from their hiding places.

[1]Bonser, T. A., Ecological Study of Big Spring Prairie; Proc. Ohio Acad. Sci., Vol. III, 1903, p. 93.

The peat is of the same character and thickness as that just described. No crops have been grown upon this tract. A composite sample from the wood lot gives the following analysis.

Analysis No. 62

		Air-dried.	Moisture-free.
Moisture		10.81	....
Volatile matter		54.12	60.67
Fixed carbon		24.53	27.51
Ash		10.54	11.82
Nitrogen		3.04	3.41
Sulphur		0.87	0.98
Calorific value	Calories	3962.00	4442.00
	B. t. u	7132.00	7996.00

It is not necessary to discuss the inferences which may be drawn from a comparison of these two samples. They show well defined relations which may be summarized as follows:

Cultivation and aëration are the two main factors in the deterioration of peat. This is due to the escape of volatile matter and the breaking down of nitrogenous and sulphur compounds. A reciprocal relation exists between the percentage of ash and that of volatile matter, and a similar relation is traceable between ash content and thermal value; an increase in ash means a decrease in volatile matter and in thermal value. Other inferences will suggest themselves to the intelligent reader.

The marked disparity in the amounts of nitrogen and sulphur which cultivated and virgin soils, respectively, contain, is, in part at least, due to the abstraction of these substances in some available form by the crops that have been raised here and shipped to distant markets. Only a small amount is absorbed, and there is still left in the soil a large aggregate of these constituents. The writer has met many farmers who reiterated the claim that large tracts of such soils have not failed for at least 30 consecutive years to produce a crop of either corn or celery, or some other adapted plant without any application of artificial fertilizers. Manure is chiefly used, and that doubtless because of its content of suitable microörganisms and fungi which aid in giving rise to organic compounds that may be assimilated by the higher plants. No charge can be made against well decomposed peat soils as lacking in durability and yet other tracts mentioned in this bulletin of equal original fertility show themselves now to be in a state of unproductiveness and are abandoned as "worthless." Such a system of farming, lacking consideration of the nature of diseases and the rational treatment of peat soils, impoverishes lands like these within a few years of the time when they were covered with a luxuriant primeval growth of grasses, shrubs and trees.

Excessive drainage and cultivation have transformed the surface peat in several localities into a fine-grained material which is readily blown about by the winds. From this cause the crops are frequently destroyed by the fine particles driven along the surface.

JACKSON TOWNSHIP

Cranberry Marsh.—West of Forest and extending largely into Wyandot County is a tract of about 500 acres which was originally a cranberry marsh. Drainage was begun in 1865 and completed within three years. The peat has been burned off almost completely. The isolated peaty strips are shallow and now contain a high percentage of ash. All of the area is under cultivation.

Testborings were made at various places in sections 20 and 21, on a line running westward into Wyandot County. The tests failed to show more than one foot of peat, much of which is impure. No analyses were made of the samples.

WASHINGTON TOWNSHIP

Hog Creek Marsh.—The extensive peaty basin, known as Hog Creek marsh, lies principally in Washington Township and extends across the line into Liberty. As in the case of the Scioto marsh, a natural ridge or glacial moraine, which crosses the county along its northern boundary line, prevents the northward drainage of the area. The marsh includes about twelve sections of land, comprising approximately 8,000 acres. An early pioneer record says: "This marsh was covered in summer with a tall coarse grass in places with a thick growth of bushes. The only benefit derived from it was a crop of flags which it produced; these were gathered in great abundance and from them the leaves were stripped and used by the coopers in the manufacture of barrels; and along the borders of the marsh some coarse grass was cut and cured for hay, and in some few places large crops of cranberries were gathered." Another early record has this to say concerning the depth of the peaty basin: "In the construction of the Fort Wayne branch of the Pennsylvania Railroad this great marsh proved a very expensive portion of the road; much trouble was experienced because of the sinking of the road bed; the material upon which to lay the ties and rails had to be hauled great distances, and after completion, when trains were running over it, every now and then a portion of the road would sink and require a large amount of material again to fill up and raise the bed of the marsh and obtain a solid roadbed. This condition of things lasted for about ten years. During that period of time many a train, it is said, was precipitated into the marsh."

This interesting account has been cited to show how varied may be the depth of a marsh before and after its complete drainage. The peat was tested by a line of borings so distributed as to show its thickness on either side of the Fitzhugh ditch and the area between Hog Creek ditch and the tracks of the Pennsylvania Railroad, all of which traverse the marsh in a nearly east and west direction. This portion is shown on the Arlington topographic sheet of the United States Geological Survey. The swamp symbol is not indicated on the map. The borings were made on sections 9, 10, 16, and 8, 17 and 20 about three miles west of Washington (Dola). The peat at all points is black, firm and well decomposed near the surface, dark-brown and slightly fibrous at the 2-foot level and gradually passes into a blackish peaty clay below a depth of 3 feet. Underneath is a plastic blue clay of great thickness somewhat darkened by fine-grained plant remains.

Bonser in discussing the comparative value of the "fertilizer" constituents of peat soil from Scioto marsh, Hog Creek marsh and Big Spring prairie, quotes the following analysis:

Analysis of Peat Soil from Hog Creek Marsh

Nitrogen as Ammonia	0.99
Phosphoric acid (P_2O_5)	trace
Potash (K_2O)	trace

The peat samples collected gave every indication of a high percentage of ash and of a low thermal value. The samples were, on that account, not transmitted for analysis. The exploitation of the deposit for fuel purposes should not be attempted, even if the quality of any of it in the occasional deeper pockets is such as to warrant utilization.

HENRY COUNTY

This county is within the Black Swamp area. The waters of glacial Lake Erie formerly covered the whole county, rising about 180 feet above the present level. The whole area is flat and its streams are sluggish. The soil shows the characters of a glacial hardpan; it is a rich, black loam through the incorporation of large amounts of vegetable matter. The loam is sandy in the vicinity of the Belmore and Blanchard ridges but in other portions of the county the soil is a clay loam.

WASHINGTON TOWNSHIP

The first settlers found the county in large part marshy. In Washington Township quicksand swamps are said to have been numerous in the depressions between the sandy knolls, and in fact such a swamp approximately 100 acres in extent may now be found in section 27. The location is shown on the McClure topographic sheet of the United States Geological Survey. The black peat is well decomposed but sandy, and averages two feet in thickness. It is underlaid by sand resting on blue clay. The area has been drained. The samples were not analyzed.

HOLMES COUNTY

High hills and deep valleys compose the greater part of the surface of the county. The valley of Killbuck Creek, which traverses the county in a north and south direction, divides it into two nearly equal parts. At the close of the glacial period this valley was one of the channels by which the waters of glacial Lake Erie, when at a much higher elevation than now, found their way into the valley of the Ohio River. The torrents which poured over the great divide farther north, carried away the surface drift and washed out the valleys. The soil of the county is, therefore, largely one derived from the disintegration of local limestones. In the western part of the county, especially along the watershed which conducts innumerable creeks into the valley of the Mohican, the drift evidences are more marked.

The peat deposits of Holmes County are not very extensive, but they differ somewhat from those of the adjoining counties. The only deposits which were examined are those in Washington Township. Near Big Prairie in Ripley Township, a buried peat bed was observed in which the peat is several feet thick. To all external appearances the peat here is of a fair quality, except that it has a layer of silt above it over one foot in thickness which probably represents the wash from the hills.

WASHINGTON TOWNSHIP

Cranberry Marsh.—This bog is about 1¼ mile northwest of Lakeville in section 26. It is nearly circular in outline and comprises little more than two acres. To the north the bog connects by a narrow channel with Bonnet Lake (Long Lake), but on the east, south and west it is surrounded by morainal hills.

The bog is an excellent example of a deposit which represents the complete closing of a lake or pond by the bog meadow association. The open water has disappeared entirely and in its place there is now centrally located a wet meadow, covered with sphagnum mosses, cranberry vines, pitcher plant, buck bean, beakrush, tall sedge (*Dulichium sp.*), tall cotton-grass, arrow grass, marsh St. John's wort and others. The occasional bushes of black huckleberry which are growing near the outer margin and the numerous young seedlings of the red maple indicate the approach of the end of the wet bog meadow. It is surrounded by a narrow concentric zone of bog shrubs. Alders were not observed, but poison sumach, chokeberry, the high-bush blueberry, winterberry, and arrowwood are the most important members of this association. The cinnamon fern with its long broad fronds and the wood fern predominate in the undergrowth. Next to the shrub zone where the peat is firm, and up the steep incline of the hills, the aspect of the vegetation changes to one in which the red maple dominates.

The peat is of an excellent quality. A number of borings were made and so distributed as to test the central portions of the bog as well as those parts lying near the margin of the shrub association. The peat is nearly all well decomposed, slightly fibrous, of a reddish brown color and averages more than 19 feet in thickness. With the available length of the sampling instrument the bottom of the deposit was not reached. Analysis No. 72 represents a composite sample from this bog.

Analysis No. 72

		Air-dried.	Moisture-free.
Moisture		6.96	-------
Volatile matter		64.35	69.15
Fixed carbon		23.30	25.04
Ash		5.39	5.81
Nitrogen		2.20	2.38
Sulphur		0.21	0.23
Iron		0.19	0.23
Calorific value	Calories	4944.00	5317.00
	B. t. u	8899.00	9571.00

The analysis shows the peat to be high in fuel value. The deposit, though small, is one of the best in the state. It is owned by Miss Grace Lovett. The location of the bog near the Pennsylvania Railroad is favorable for commercial development. The nearest shipping point is Lakeville, one and one-fourth miles distant.

Mud Lake. — A somewhat extensive peat deposit surrounds the open water of this pond in section 26, and extends over the line into Lake Township, Ashland County. An account of this bog and the analysis of the peat sample are given on page 32, in the discussion dealing with the deposits of Ashland County.

HURON COUNTY

The distinctive topographic feature which characterizes the surface of Huron County is that of old water plains, diversified by sand dunes, old lake beaches and various channels excavated by present streams. Glacial Lake Erie covered much of the surface of the county near the close of the ice age. As the waters receded the terraces were formed, and each for a long period constituted a shore marsh which was later occupied by shrubs and trees. In Huron County the deposits all represent the final stages in the process of peat accumulation, the complete closing of the ancient lakes by plants. The replacement of one plant association by another in definite successions is, however, still going on. The conditions, as described for the New Haven marsh, illustrate the sharply drawn lines of the advance of shrubs, trees, and meadow plants. The vegetation zones have been maintained for a considerable period during which existing conditions were constant. Changes have taken place only recently.

LYME TOWNSHIP

The upper beaches of glacial Lake Erie were long subjected to the action of shore waves and wind. Their surface is occupied by sand dunes which in places rise to a height of 30 feet. The north side of the ridge exhibits the irregular, winding outlines of an old lake beach. The south side is bordered by irregular billowy dunes of fine sand with waved lines of stratification formed by the wind. Back of the beach extends the peaty soil of a former marsh which was caused by the ridge acting as a barrier and preventing the northward drainage of the basin. The deposit extends under the dunes because the sand was drifted over it. The peaty "prairie" rests upon a heavy subsoil of bowlder clay. Near Monroeville in Ridgefield Township, the marsh is said to have contained abundant remains of coniferous trees.

The area deserves special attention and a much more extensive study than could be given it. Testborings were made at various places, but the peat beds seem generally very shallow, a foot or slightly more in depth. It is evident that drainage, followed by drying, cultivation and occasional fires, has reduced the thickness of the peat bed considerably.

The samples were not analyzed. The peat is structureless and well humified, but too high in mineral matter; this constitutes the principal drawback to its commercial development. The difficulties which were met in reclaiming the peat deposit for agricultural purposes, the interpretation of the character of the soil disease and the remedy applied, are illustrated in the following account given by Read in his report on the Geology of Huron County.[1]

"While the peat body of this level land reclaimed from the old swamps is exceedingly fertile, there is a remarkable exception in a large tract north of Monroeville, and extending into Erie County, to which my attention was called some years before the survey was authorized. The soil is a fine black, peaty mold, presenting nothing to the eye to distinguish it from the productive corn lands surrounding it. It was cleared and put under cultivation, upon the supposition that it was of equal value with the adjacent lands; but it refused to tolerate grass, or corn, or any valuable crop. Here and there an apple tree sprang up, spontaneously seeded, and grew vigorously; but the principal crop was a small one—a light growth of weeds. The effort was made to ameliorate a part of it by a more thorough drainage, and ditches were opened through it at considerable expense; yet the land was nothing bettered, but rather grew worse. The soil is comparatively thin, the bed rock coming near the surface; but equally thin soils, in other places in the neighborhood, are productive, and I am confident this is not the real cause of its infertility. A washing of the soil showed, with litmus-paper test, a decided acid reaction, and selected specimens gave the taste of

[1]Read, M. C., The Geology of Huron County, Geol. Surv. Ohio, Vol. III, 1878, pp. 293-294.

acid when touched by the tongue. The vegetation, also, indicates the presence of acid. The soil has every element of fertility, and there can be little doubt that this deleterious substance is the sole cause of its sterility. If this is so, it only remains to inquire what is the origin of this acid, and how it can be removed from the soil, or have its injurious properties neutralized. The underlying rock is the Huron shale, which is filled with nodules and concretions of the bisulphide of iron. Wherever this is exposed to the joint action of air and water, it is decomposed, the sulphur set free, which, uniting with the oxygen of the air, produces sulphuric acid. These changes are facilitated by cultivation, and by more perfect drainage of the soil, so that the steps taken to improve the soil only aggravated the evil. If this is the cause of the difficulty, the remedy is easily found—a generous dressing of ashes, or of quicklime, will be sufficient. The lime, uniting with the acid, will form a sulphate of lime, or "plaster," of itself a good fertilizer. The alkali must be well mixed with the soil, and the application may have to be repeated, until all the pyrites within reach of atmospheric influences has decomposed, and yielded up its sulphur. In a similar case in Trumbull County, a single application, made some ten or twelve years ago, was sufficient to neutralize the acid, and no repetition of the remedy has been required. The amount of lime needed can only be learned by experiment."

HARTLAND TOWNSHIP

There were formerly a number of marshes and swamps in this township. The largest of these were known as Canterbury Swamp, Cranberry Marsh and Bear Swamp. The first was over two miles in length, and about one-half mile in width. It lay southeast of Hartland. Cranberry Marsh lay north of Hartland and contained about 100 acres. They are today shallow deposits, in large part burned over, well drained and under cultivation.

RICHMOND TOWNSHIP

The New Haven Marsh.—This bog is one of the most extensive peat deposits in the State. It represents an old water plain on the lower terrace of glacial Lake Erie. A tongue of the glacial lake reached far into the southern part of the county at that time. The depression between the two almost parallel shore lines of glacial Lake Erie constitutes the deeper portion of the peat deposit. The bog covers the southwestern corner of the county and contains about 20 square miles. It is six miles long from east to west, and over three miles in width, covering an estimated area of 5,500 acres in Richmond Township, 3,500 in New Haven and about 800 in Auburn Township, Crawford County (Fig. 5). Not all the territory is now underlaid by peat, but within the memory of the older residents the portion in Crawford County is said to have extended over 1,000 acres more than at present. The bog is undoubtedly one of the largest and best peat deposits in the State. It is well located between the Baltimore & Ohio Railroad, the Northern Ohio Railroad and the Sandusky branch of the "Pennsylvania Lines."

The New Haven marsh has the appearance of an extensive grassy prairie with "islands of trees and bushes." The bog feeds a small stream known as "Marsh-run," which is a tributary to the Huron River. It also gives rise to a stream flowing in the opposite direction and appar-

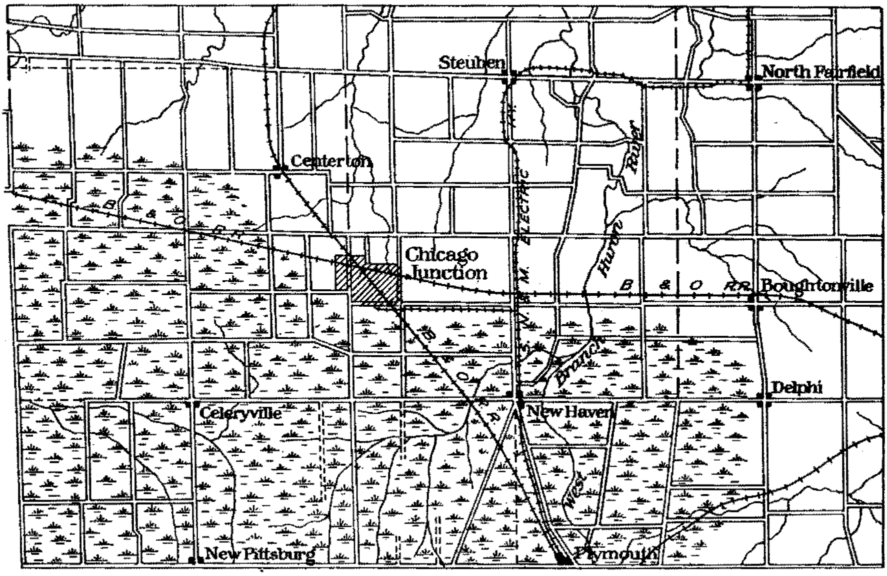


Fig. 5.—Map showing the approximate area and location of New Haven Marsh, Huron County.
Scale, 1 inch = 3 miles.

ently into the Ohio River. The connection is not so distinctly marked, yet it is a general characteristic of the streams in this part of the State which have their origin near the Ohio divide. They take their common origin in marshes where they receive the surface drainage from the higher lands and then flow in opposite directions.

In the northwest portion, fires have swept repeatedly over a large part of the bog. Tickseed, sunflower, blue vervain and ragweed predominate on the area most severely burned over. Boneset, goldenrod, and sedges occur in relatively smaller numbers though quite abundant. The peat is brown and fibrous at a depth one foot below the surface; underneath this layer is a well decomposed, structureless variety, about eight inches thick, resting on a grayish blue clay underlaid by sand.

In the areas where slight surface fires prevailed, the peat is of greater thickness, averaging along the margin 7 to 8 feet. It is generally wet and fibrous near the surface, and dark-brown, less fibrous and partly decomposed below. The vegetation consists principally of shield, cinnamon and flowering ferns, cotton grass, beak and bog rush. Scattered among them are small thickets or isolated plants of poison sumach, willow and poplar, with such shrubs as the wild rose, the chokeberries and meadow sweet. In many places twig rush, and occasionally spike rush, is the dominant plant, giving a distinct physiognomy to the area.

A number of testborings were made on lines running east along the northern part and south across the central portions of the bog. Near the point where both the creek, a branch of the Huron River, and the ditch, running north and south, have their origin, the area is wet and low. Twig rush is the prevailing plant; on the higher parts of the marsh, about 300 feet farther south along the ditch, shrubs like dogwood, elderberry with meadow rue, trumpet weed and king fern, prevail. The twig rush society grows on peat 11½ feet deep, brown in color, plastic, thoroughly decomposed, with fragments of well decayed wood. At a depth of 13½ feet occurs a blackish clayey peat with an admixture of silt. The shrubs are more abundant on peat which is firm to a depth of 11 feet. It rests on a layer of clay 2 inches deep over a blackish sand.

Along the creek in an easterly direction, at a point which probably indicates a corner of a section, the marsh is wet as the following plants show—bluejoint grass, water parsnip, shield fern, swamp loose-strife, arrow head (*Sagittaria latifolia*), and several sedges. Poison sumach and dogwood, golden rod, hedge bindweed, royal fern, meadow rue (*Thalictrum purpurascens*), violet and skull cap occur on drier places. The peat substratum is generally a fibrous, light-brown turf, showing roots and root-stocks to a depth of 9 feet. The material is well decomposed just above the 9-foot level, but more coarsely fibrous below. Fragments of roots, leaves and disintegrating wood are frequently encountered at the lower depths. The peat is wet and plastic toward the bottom and at 11 feet below the surface merges into a bluish sandy and silty clay.

The greater part of the area was probably surrounded originally by the maturer phases of bog plant successions. Shrubs and trees were undoubtedly the dominant elements before fires produced the many changes which are apparent. At present the interior portions of the bog, which have been burned over by unscrupulous trespassers even as late as the fall hunting season of 1909, show bog meadow and bog shrub associations in various stages of rejuvenation, and "tree islands" on the higher levels of peat. It is still possible to get some idea concerning the successions of vegetation and the manner in which the plants have built up the peat deposit.

About midway in the first quarter-section of the township a cranberry-sphagnum meadow covers a fairly large area. In places a sedge (*Carex riparia* or *C. utriculata* ?) gives distinct character to the meadow, forming an easily differentiated society. In wetter portions the twig rush is dominant. The sprouts of arrowwood (*Viburnum dentatum*) and black alder (*Ilex verticillata*) form occasional intrusions into the cranberry meadow and a scrubby willow (*Salix myrtilloides* = *pedicellaris*), was also frequently noted. The cranberry vines and the sphagnum mosses are by far the more active plants and yet there were patches where these two were overgrown and even suppressed by the prostrate bramble (*Rubus hispidus*). In places the scrubby willow and similar small bushes were completely covered.

A testboring in this area indicated at the depth of 3 feet a light-brown, fibrous, poorly decomposed, matted peat. At the 5-foot level the peat is somewhat darker; at the 7-foot level very wet, light-brown, fibrous and composed in part of fine roots of sedges; at the 9-foot level the peat is fine-grained, blackish brown and considerably firmer. Below this is a dark-brown fine-grained material with wood fragments which contains seeds and roots of water plants near the 13-foot level. At a depth of 15 feet the peat is more or less fine-grained, somewhat sandy, with bits of wood and the seeds of water plants. The bottom layer, at a depth of 17 feet, is a thin bed of clay, resting on a coarse sand and darkened by plant remains.

West of the meadow toward one of the larger "tree-islands" the bog shrubs are clearly the intermediate vegetation succession. The high-bush blueberry predominates, and poison sumach and chokeberries are less abundant. The undergrowth consists mainly of stragglers from the bog meadow, tall sedge (*Dulichium sp.*), cotton grass, bog sedge (*Carex sterilis*), shield fern, patches of cranberry and sphagnum with the prostrate bramble, several species of orchids (*Pogonia ophioglossoides, Calopogon sp.*) and the larger blue flag (*Iris versicolor*). The cinnamon fern and the royal fern are fairly abundant.

The peat is rather fibrous but otherwise well decomposed to a depth of 7 feet. At the 9-foot level the material is coarser, lighter in color, and continues that way to the 11-foot level. Below this at a depth of 13 feet, the peat merges into a plastic, fine-grained, blue clay.

The "tree islands" on the higher levels of peat rest, apparently, on low knolls and ridges. The principal trees are red maples with an undergrowth of shrubs and, occasionally, small patches of bog meadow plants. The effects of fire are seen everywhere. The area presents many depressions in which the cattail, with a number of water plants, is making an appearance.

The samples from the various localities just described give the following analysis:

Analysis No. 42

		Air-dried.	Moisture-free.
Moisture		8.77	-------
Volatile matter		54.50	59.73
Fixed carbon		26.79	29.39
Ash		9.94	10.88
Nitrogen		2.60	2.84
Sulphur		0.86	0.95
Calorific value	Calories	4520.00	4952.00
	B. t. u	8136.00	8914.00

There are several places along the southern and eastern portions of the bog, near the road leading to Chicago Junction, in which the reed

(*Phragmites communis*) is very common and spreads densely over the surface. Several testborings were made about one mile north of the Crawford County line and at points toward New Pittsburg. The peat is well decomposed at the surface; below this, at the 3-foot level, it is dark-brown, firm and contains quantities of rhizome fibers of the reed. This texture continues to a depth of 9 feet. The peat below this level was not determined, since shallow areas became more general toward the county line. An analysis of the composite sample is as follows:

Analysis No. 64

		Air-dried.	Moisture-free.
Moisture		9.24	-------
Volatile matter		49.81	54.87
Fixed carbon		23.24	25.62
Ash		17.71	19.51
Nitrogen		2.45	2.70
Sulphur		0.82	0.90
Calorific value	Calories	3756.00	4138.00
	B. t. u	6761.00	7448.00

The high ash content and the low thermal value render the peat of questionable commercial value for fuel, but not for agricultural purposes.

LAKE COUNTY

The general surface of the county is an almost uniformly inclined plain, sloping toward Lake Erie with an average descent of about 5 feet to the mile. It is quite extensively modified by the erosion and drainage of numerous small streams. The surface also exhibits old lake beaches, mostly composed of unstratified clays, but irregular and not well defined. In many places the ridges are masked with the debris of bluffs. The soil is generally a stiff clay loam, containing much vegetable matter. This indicates that extensive marshes for a long time occupied the areas south of the old lake beach. At Painesville the "south" ridge is in places composed of coarse stratified gravel modified by subsequent water action, while the "north" ridge is of finer, water-washed and drifted sand, frequently of the character of irregular sand dunes. A short distance from this place the north ridge is less disturbed and changes but little under the influence of the wind. On the north side is an extensive deposit of peaty material which until recently had an average depth of six feet. Large amounts of roots and trunks of tamarack and pine are intermingled with the debris. The soil has been used largely by gardeners and nurserymen. The deposit is now very shallow in most places and the percentage of clayey sand is sufficient to injure its value as a commercial product.

The northern portion of Mentor Township has a marsh of approximately 800 acres. The location and area are shown on the Mentor topographic sheet of the United States Geological Survey. The basin is apparently the broad channel of an old river. The banks on each side are abrupt and about a half mile apart, but nearer the lake this distance increases to a mile or more. The intervening marsh contains areas of open water. At the lake shore a sand bar stretches from one bluff to the other, through which channels are cut at periods of heavy rainfall. The thickness of the deposit and the character of the vegetable accumulation have not been determined. It is undoubtedly well worth a more detailed study on account of its probable relation to an early drainage system, and also because of its interest to the ecologist.

LICKING COUNTY

The county has several well marked topographic features. The northeastern and the southwestern parts constitute an undulating table-land covered with unmodified glacial clay. The southeastern part, like the northeastern, is hilly with deep, narrow stream channels. Farther west and south a series of low hills project into plains. A deep pre-glacial valley from the north extends southward to Newark, where it divides and is now occupied by the north and south branches of Licking River. The latter flows with a reversed current to join the main stream at Newark. Along the valley of the old channel the surface is in many places occupied by bogs and marshes. Buckeye Lake marks the higher elevation of this area.

Peat covers over three thousand acres in this county. Most of the original "prairies" and "swamps" had the characteristics of wet marshes and bogs. Some of the more important were in Bowling Green, Lima, Liberty and Hartford townships. Most of the deposits are today not over two feet thick; the underlying clay is heavy, yet light-colored. Almost all of the peaty areas have been plowed and are now under cultivation.

In Harrison Township, two miles southeast of Kirkersville, the surface is marked by several peaty areas, of which the largest is "Bloody Run Swamp." The smaller ones are now merely depressions in the fields and are under cultivation. Bloody Run Swamp covers an area of 400 acres, of which 250 have peat with an average thickness of 12 feet. The deposit rests on yellow clay 3 feet deep; underneath the clay the borings for wells indicate gravel. Twenty years ago a bog forest of red maple, swamp ash and other deciduous trees with an undergrowth of poison sumach, willow and bog shrubs, is said to have been the characteristic vegetation.

In Washington Township a few miles southeast of Utica, an extensive deposit was known as "Cranberry Prairie." Weathering and cultivation have reduced this to a shallow layer of well humified peat.

LICKING TOWNSHIP

Buckeye Lake.[1]—The area and location are shown on the Thornville sheet of the United States Geological Survey. The lake basin lies near the margin of the great ice sheet, and up to 1828 was a swamp covered with large trees. The area given by early surveys approximates 4,000 acres.

The present lake was formed in 1830 to serve as a reservoir for the Ohio and Erie Canal. A dike was built around the west end and a part of the north side of the swamp, which permitted a rise of the water surface 8 feet higher than the original level. Most of the peat mat with the tree-cover was not sufficiently elastic to rise more than a few feet. It remained attached at the sides and consequently disappeared beneath the rising water. The larger number of trees then standing soon died and fell into the water, where they remained beneath the surface. They were gradually cut away and only recently the greater part of the stumps has been removed.

However, not all of the original vegetation disappeared with the inundation of the area. Near the northern bank and about one-half mile southeast of Buckeye Lake is a bog island, approximately one-tenth the dimension of the lake (Plate III, A). With the rising of the water level the lighter fibrous top layer separated from the grounded mat and thus the vegetation survived. There are a number of smaller floating islands and periodic ones. Some of the former which were separated through the action of waves beating against the mat of vegetation, were set adrift by the wind and floated about until anchored in shallow water. The periodic islands are large peat masses, devoid of any vegetation, which usually rise from the water in summer and sink again in fall. Such islands owe their appearance both to the activities of gas-producing microörganisms and to the descent of the warmer surface water.

Borings, about 50 in number, which were made at various points on Cranberry Island to determine the thickness and character of the peat, indicate an average thickness of 30 to 35 feet along the southern shore of the bog island and 11 feet along its northern shore. Tests made to a depth of 40 feet at the southernmost points of the island and in the lake south of it failed to reach bottom. The borings were made at a time when, for purposes of repair, the water surface of the lake was lowered five feet below the normal level and gave the following results:

[1]Detmers, F., An Ecological Study of Buckeye Lake; Ohio Academy of Science, 1912.

TABLE 2

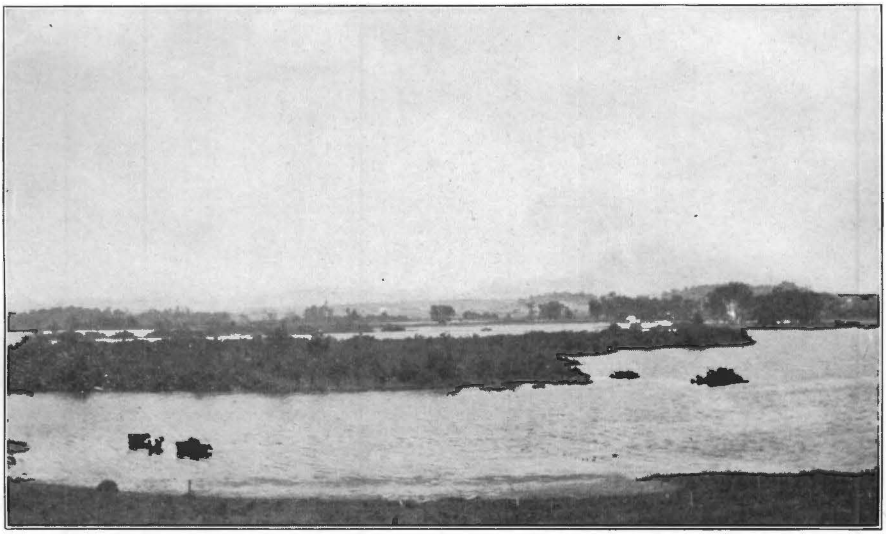
Analysis of Peat Specimens from Cranberry Island, Buckeye Lake, Ohio.

Analysis Nos.	Station.	Depth ft.	Depth meters.	Description of peat samples.
5	Central zone; sphagnum-cranberry	5	1.5	Brown, fibrous peat; mostly cranberry, sphagnum, and sedges.
7		14	4.2	Brown, non-fibrous, plastic peat with diatoms and shell marl.
8		25	7.5	Dark-brown, well decayed, finely granular peat; algae (?) and filling from marginal borders.
9		40	12.0	Nearly black, non-fibrous, clayey peat.
11	Maple-alder zone	6	1.8	Dark-brown, slightly fibered peat, coarser fibered below.
12		10	3.0	Brown and fibrous peat.
14		18	5.4	Dark-brown, well decayed, finely granular peat with shell marl.
21		31	9.3	Fine sand with clay underneath.
22	Northeast station	5	1.5	Brown, fibrous peat; mostly cranberry, sphagnum, and sedges.
26		18	5.4	Granular peat; very sandy above, marly beneath.
27		28	8.4	Sandy marl; blue clay beneath.
28	Southeast station	5	1.5	Brown, coarse fibrous peat.
29		10	3.0	Dark-brown, slightly fibrous; a lighter colored coarse fibrous peat underneath.
30		20	6.0	Brown, fibrous peat containing roots and rhizome fragments.
31		40	12.0	Black, plastic, non-fibrous peat; bottom not reached.
32	Southwest station	5	1.5	Light-brown, coarse fibrous peat.
36		20	6.0	Plastic, fine-fibered, dark-brown peat containing shell marl.
38		40	12.0	Black, plastic, non-fibrous peat; bottom not reached.
40	Northwest station	5	1.5	Light-brown, fibrous peat, composed of sphagnum and other bog plants.
42		20	6.0	Fine-fibered, dark-brown peat.
45		28	8.4	Sandy gravel underlaid by blue clay.
48	Lake station	6	1.8	Dark-brown, slightly fibrous peat.
49		40	12.0	Black, plastic, non-fibrous peat; bottom not reached.

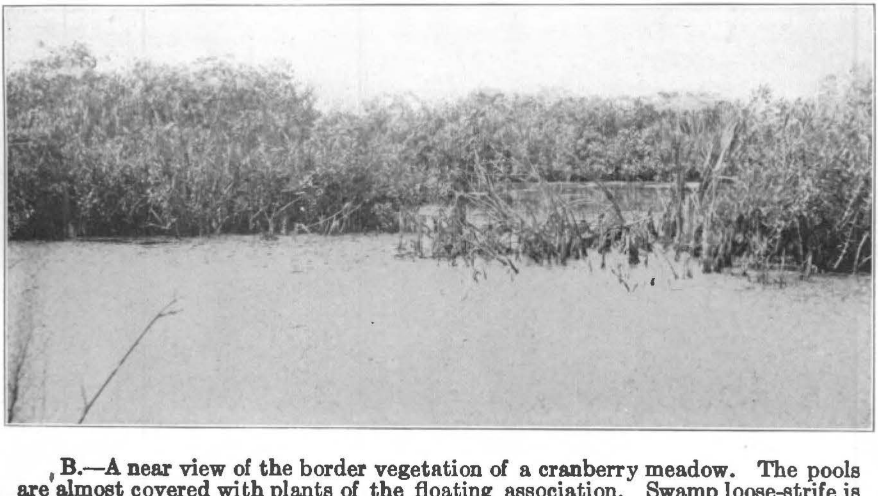
The accumulation of vegetable matter has been sufficient to fill the lake basin with a layer of peat of considerable depth. The deeper portions have been largely reduced by humification to the form of a black humus, a semi-liquid muck. Its fineness of grain and peculiarly soft consistency suggest that it is in part made up of the remains of algae and in part a filling from the border of the lake that has been spread over the bottom. The upper portions are lighter in color and very fibrous, loosely felted in structure and have a matted appearance. As the island is sounded from top to bottom, the samples show a progressive change in color from light to darker shades and in texture from coarse and loose to fine and more compact peat which is always saturated with water. In some places this sequence is repeated; that is, below the peat muck there occurs a second fibrous, brown layer followed by muck or clay. The escape of gases is very noticeable during the testborings, and also the staining of the brass peat sampler to a bluish purple bronze, indicating the presence of a gas like hydrogen sulphide. Only a small deposit of shell marl has thus far been found in places underlying the peat substratum. The *Characeae* and *Cyanophyceae* concerned with this process are not abundant enough to be considered as agents in the aggradation of the basin. The lake bottom is of clay and in places somewhat sandy. The thickness of the peat in this morainal depression indicates, therefore, that the vegetation must have obtained an early foothold.

The Border Zone.—The outermost growth which immediately borders the open water and forms a more or less broken fringe around the island is for the most part hydrophytic (Plate III, B). A considerable admixture of shrubs occupies the firmer parts of the peat substratum.

Along the southern shore swamp loose-strife (*Decodon verticillatus*), and in places cattails (*Typha latifolia* and *T. angustifolia*) dominate. This facies has for its principal and secondary species *Hibiscus moscheutos, Sagittaria latifolia, Polygonum emersum, Scutellaria galericulata, Lathyrus myrtifolius, Bidens discoidea, B. cernua, Potentilla palustris, Campanula aparinoides, Galium triflorum, Cicuta bulbifera, Peltandra virginica, Radicula = Roripa palustris, R. aquatica, Dianthera americana* and others. They are generally abundant with *Decodon* and *Typha* forming a dense growth, which attains a height of from 2 to 6 feet above the substratum. The vertical zonation is that of the differences in habit of growth of the individual species. The members differ widely from one another both in external features and from their demands upon the environment. In these regards the vegetative shoots adapt themselves but little to the prevailing exposed conditions. Growing upon a peat substratum whose depth and physical characteristics are in every way like that of the other plant zones to be described below, the xerophytic type and quality are least marked in this vegetation. The well decomposed peat soil of the border zone permits here a luxuriant growth. The plants are able to secure all of their raw food materials from the water and air and build their own substratum. The large water capacity of peat, the absence of a mineral soil, the smaller percentage of oxygen in the water, and the incoherency of the substratum afford no precarious conditions for growth. Here the toxicity of the substratum and the consequent physiological aridity are least marked. It is evident that the dilution and the capacity for absorption of soluble salts by the humus soil along the margin of the island corrects any harmful effect.



A.—Cranberry Island in Buckeye Lake.



B.—A near view of the border vegetation of a cranberry meadow. The pools are almost covered with plants of the floating association. Swamp loose-strife is the pioneer mat former.

The following is an analysis of peat from the border zone of the island. The texture of the material is indicated in table 2 (p. 87).

Analysis No. 43

		Air-dried.	Moisture-free.
Moisture		9.90	-------
Volatile matter		55.53	61.63
Fixed carbon		24.43	27.11
Ash		10.14	11.26
Nitrogen		2.00	2.21
Sulphur		0.58	0.64
Calorific value	Calories	4065.00	4512.00
	B. t. u	7317.00	8122.00

Unless the lake is drained, it would be necessary to excavate the peat by pumping or dredging.

The *Decodon-Typha* association has a transition appearance, for a considerable admixture of plants such as *Rosa carolina, Cephalanthus occidentalis, Cornus stolonifera, Salix discolor, S. nigra, S. pedicellaris, Alnus rugosa, Ilex verticillata, Pyrus melanocarpa* = *Aronia nigra, Rhus vernix,* and various secondary dependent associates among which are *Rubus nigrobaccus* and *Viola blanda,* occupy the firmer parts of the marginal zone and form an almost continuous fringe, the *Alnus-Rhus* association. In places it extends diagonally across the bog island as scattered dense thickets. This community of plants presents on the whole very little zonation within itself. It constitutes a zone of varying width, 5 to 30 feet and more, and attains a height of 8 to 12 feet. In only a few places along the southern shore this type of bog shrub association is absent altogether and is replaced, as has been stated, by *Decodon* and *Typha.* The edaphic conditions of this part of the habitat seem to approximate those of the undrained swamps as described by Cowles.[1] Nearer the lake there is a tendency toward the segregation of *Decodon verticillatus* and *Hibiscus moscheuotos.* Of the two, the former is more vigorous and occupies the deeper water. *Rosa carolina* prefers the outer border also, but clings quite closely to *Alnus rugosa* and *Cornus stolonifera.* Contemporaneous with the thicket-formers, various species of lianas invade the association. The mature thickets are often covered with an impenetrable growth of tangled vines of *Apios tuberosa, Solanum dulcamara, Convolvulus sepium, Ipomoea sp.,* and *Cuscuta gronovii. Cephalanthus occidentalis* does not constitute a large part of the shrub association. Together with *Decodon* it is found often indiscriminately mixed with facies in the central zone. In fact, the differences in the associations are to be seen largely in the ratios between the numbers of individuals present and not in their absence from either group of plants.

The Maple-Alder Zone. — With the maturity of the plants, a gradual change in the environmental conditions for the plants takes place. The annual leaf-fall covers the substratum with a visibly thicker layer of vegetable material, rich in organic matter, and is followed by the growth of fungi and bacterial organisms favorable to succeeding plants through the formation of available nitrogen. Like snow and ice, the covering of fallen foliage reduces the extremes of soil temperature,

[1]Cowles, H. C., Physiographic Ecology of Chicago and Vicinity; Botanical Gazette, Vol. XXXI, 1905, pp. 73-182.

suppresses the growth of cranberry, sphagnum mosses and similar plants from the adjoining central zone, and improves the production of a kind of humus of great significance to the animal life as well. Moles, earthworms, snails and insects are not uncommon in this zone. The shade of the trees during summer and autumn checks extreme evaporation, and thus reduces the transpiration from the herbs and shrubs beneath the trees. Through the combined action of these and various other agents, there is a corresponding rearrangement of some species and the disappearance of others. In places along the margin, the peat substratum is firmer, fairly well above the level of the lake and comparatively better drained. These conditions are sufficiently established at the southeast side of the island to be characterized as the maple-alder zone.

The bog tree association is quite prominent and though not extensive is still a strongly marked zone. The most conspicuous plants are large-sized maples (*Acer rubrum*), alders (*Alnus rugosa, Ilex verticillata*), the chokeberry (*Aronia nigra = Pyrus melanocarpa*), black cherry (*Prunus serotina*) and poison sumach (*Rhus vernix*). Oaks (*Quercus palustris, Q. imbricaria*), ashes (*Fraxinus nigra*), and the silver maple (*Acer saccharinum*) are still relatively rare. The trees are surface-rooted but the roots do not penetrate to a depth of more than one foot. They spread out in all directions from the trunk and are of sufficient size and length to withstand the mechanical strains due to the action of air currents. The association is still an open community of plants and has four distinct vertical layers. The trees cast a relatively dense shade in which grow seedlings and young trees of oak and maple and a variety of shrubs and herbs. Fairly abundant are *Sambucus canadensis, Impatiens biflora, Rubus sp., Viola blanda, Aspidium spinulosum, Osmunda regalis, Carex scirpoides, Aspidium cristatum, Habenaria clavellata* and *Bartonia virginica* with a ground cover in part of *Pallavicinia lyellii* and *Cephalozia sp.*

The following is an analysis of peat from the Maple-Alder zone. The texture of the material is indicated in table 2 (p. 87). An analysis of the bog water is given in tables 29 and 30; that of the fertilizer constituents in table 32.

Analysis No. 40

		Air-dried.	Moisture-free.
Moisture		7.87	-------
Volatile matter		68.91	74.79
Fixed carbon		19.66	21.35
Ash		3.56	3.86
Nitrogen		2.32	2.52
Sulphur		0.26	0.28
Calorific value	Calories	4267.00	4632.00
	B. t. u	7681.00	8338.00

There is protection from strong air currents and in the changed light, heat and moisture conditions the plants offer a striking contrast to the vegetation next to be described. Many of the herbaceous and shrubby species occur only sparingly and are really constituents of the other societies of the border zone. In the numerous maple and oak seedlings evidence is seen that the *Rhus-Alnus* association will not continue to occupy the habitat. The lowering of the water table due to the continued addition of debris and leaf humus will hasten the advent of better soil, drainage and shade conditions. Alder, poison sumach and their associates will find the new conditions unsuitable; they will disappear, leaving the zone more typically an oak-maple-ash association. It is improbable that this coming vegetation group represents a climax forest for filled lake basins in this locality. There are limited portions of Cranberry Island which in the course of years are bound to revert to the central-zone bog type, and that perhaps intermittently, for a settling and shrinkage of the numerous water pockets in the peat substratum will continue until all of the lower portions have become firm and compact. With continued accumulation of forest litter, the soil conditions will finally become drained and more xerophytic, to an extent that will constitute an ecological habitat considerably different from that existing in the neighborhood. Should the water level remain constant the amount of upbuilding will be limited to the height to which the water will rise through the accumulation of peat, and will supply the growing plants at the surface with the necessary physiological water. It must not be assumed, therefore, that the development of a mesophytic forest could continue in the same direction indefinitely.

The Central Zone.—This is a cranberry-sphagnum meadow, (Plate VII, A), situated in the middle of the island. It occupies the larger part of the island and in its floral structure is very distinct.

The plants consist principally of *Vaccinium* = *Oxycoccus macrocarpon* and several species of *Sphagnum*, with *Rhynchospora alba*, *Eleocharis obtusa*, *Aspidium* = *Dryopteris thelypteris*, *Dulichium arundinaceum*, *Carex comosa*, *C. interior*, *C. filiformis*, *C. limosa*, *Scheuchzeria palustris*, *Juncus canadensis*, *Eriophorum virginicum*, *Osmunda cinnamomea*, *Drosera rotundifolia*, *Menyanthes trifoliata*, several orchids and other light-demanding forms variously grouped. The surface is characterized by hollows and elevations. The latter are due, in the opinion of the writer, to various causes: (1) in part to the upward growth of sphagnum competing with cranberry, (2) in other places to a mutual protection which is afforded by the massing of forms of similar height against excessive loss of water, (3) in still other places cranberry and sphagnum which are growing beneath shade-producing forms, notably around ferns and invading maples and sumachs. Here they possess the ability to grow in such a way as to give rise to a thick, soft mass which rises to a considerable height, but more at the center than at the edge. The maximum height to which hummocks of sphagnum can grow is in part limited by the vertical saturation gradient of the water content in the air. The vertical level of this vegetation is otherwise fairly uniform, varying only between 6 and 15 inches above the peat substratum and forming a low, dense, compact growth. The taller grasses and sedges and the occasional bushes of *Gaylussacia baccata*, *Pyrus melanocarpa*, and *P. arbutifolia* occur chiefly scattered and as open facies. They do not dominate the general vegetation enough to interfere with the transpiring organs of the plants at the lower level.

A more detailed study of the distribution of species in the lower stratum shows habits of growth giving rise to layers sufficiently defined to show vertical zonation; especially the differences in height of growth in the sphagnums, *Gaylussacia* and *Vac-*

cinium in areas of varying physiological aridity, show that the plants are adapted to a given average supply of water. But in the zone under consideration, the differences in habit of form shade into each other and in consequence are less distinct than those in the adjoining border zone. The prevailing, grass-like growth-form and the general reduction in size of leaves assumed by the different species are in harmony with the environment. This harmony expresses itself not only in external features but also in the anatomical structure. As an ecological unit the community of plants, identical in type but different in floristic composition, exhibits well within itself the impress of its conditions of life.

That the plants are adapted to a given average supply of water but with great specific differences among themselves, is further seen in the frail growth of *Cephalanthus* and *Decodon*, in the small trees of *Acer rubrum* and *Rhus vernix* and in the stunted forms of various other invaders from the neighboring plant societies which occur scattered throughout this zone. For the past few years thousands of maple, sumach and alder seedlings have been observed sprouting, and yet few have succeeded to live beyond the first year. Of those which succeeded, the stunted growth, the numerous dead branches and the ragged crown of foliage, are a clear illustration that the resistance offered by the invaders to the toxic conditions of this habitat is but slightly effective.

There are several small ponds in the cranberry-sphagnum zone where the dominance of *Decodon* and *Typha* as important members of the border vegetation is especially conspicuous. *Decodon* is particularly well adapted for making an advance outward upon the water by the curvature at the tips of the slender mature stems. From the submerged part, roots arise in considerable numbers, and new plants develop which remain moored to the parent plant for a year or two. As soon as the stools are built, they become the habitat of a number of forms such as *Bidens cernua*, *Polygonum hydropiperoides*, *Cyperus strigosus*, *Impatiens biflora*, *Peltandra virginica* and others. These with *Decodon* and *Typha* seem however unable to persist, for dead stems of *Typha* and remains of stools of *Decodon* may be seen in the cranberry-sphagnum association immediately behind this border vegetation.

The following is an analysis of peat from this zone; the texture of the material is indicated in table 2 (p. 87). Analysis of the bog water is given in tables 29 and 30; that of ash in table 32.

Analysis No. 41

		Air-dried.	Moisture-free.
Moisture		9.23	-------
Volatile matter		60.90	67.09
Fixed carbon		22.19	24.46
Ash		7.68	8.45
Nitrogen		0.92	1.01
Sulphur		0.39	0.43
Calorific value	Calories	4349.00	4792.00
	B. t. u	7828.00	8626.00

The sphagnum-cranberry association should not be regarded as an intercalation. The organic matter deposited by past generations of plants shows that sphagnums, cranberry and their associates occupied this surface long before the maple-alder zone was formed. It is, therefore, an earlier and normal stage of succession under conditions of development and a combination of factors which favored persistence and succession in that direction, and which are not suitable even today for the ecesis of a shrub association or for germination and growth of the seeds blown over in great quantities from the wood lots and fields surrounding the lake.

The vegetation in the central zone agrees very largely with plant societies in bogs and swamps of more northern regions. Many other boreal plants which were doubtless concerned in the early development stages of the local bog are now extinct. This is especially true of the pitcher plant (*Sarracenia purpurea*), the creeping snowberry (*Chiogenes hispidula*), wild rosemary (*Andromeda polifolia*), leather leaf (*Chamaedaphne calyculata*), labrador tea (*Ledum groenlandicum*), pale laurel (*Kalmia polifolia*) and larix (*Larix laricina*). These plants are still found in bogs in the northern part of the State. A number of them have been recently transplanted and are now in good condition on the island.

LOGAN COUNTY

The whole county, notwithstanding its high elevation, was originally wet and swampy. Numerous small lakes and ponds still exist. In Rush Creek Township a bog-like meadow formerly extended northward about three miles from Rush Creek Lake and about the same distance southeast. Most of the deposit is relatively shallow and has been under cultivation for some years. Shell marl underlies it.

The Cranberry Marsh near Lewiston in Washington Township was probably among the larger peat deposits of the county. It covered an area of about 250 acres and had an average depth of 5 feet. Sphagnum mosses in great quantities were taken up and shipped to florists and nurserymen for use as packing material. The marsh was drained about twenty years ago and a large part of it is now under cultivation.

In Zane Township, Mill Branch and Mackachack creeks take their rise in a low wet meadow. The peaty deposit covered 100 acres, most of which is now under cultivation.

There are numerous small peat deposits and sink holes in Liberty, McArthur and Union townships. The debris is well decayed and humified and averages a thickness of 2½ feet.

LORAIN COUNTY

Peat is found in several localities as may be seen from an inspection of the swamp areas of the Vermilion and Berea topographic sheets of the United States Geological Survey. All of the basins are small and in large part under cultivation. Brighton, Avon and Camden townships have small deposits which were doubtless once cranberry marshes. The time at the writer's disposal was too short to permit testborings.

LUCAS COUNTY

The surface of Lucas county is more or less flat and level. Oregon Township and the eastern part of Washington form a part of the tract to which the name "Black Swamp" has been applied. The soil is a fine clay, black with decayed vegetation and varied by streaks having an admixture of sand.

The greater portion of Spencer and Springfield townships consists of a deep sand presenting all the features of dunes. The sand was accumulated by the currents of glacial Lake Erie and deposited by the waves in beaches and later built into dunes. The ridges are covered by an open growth of oaks. The marshes lie in depressions that originated between the sand dunes and occasionally contain small deposits of peat. North of Holland, in Springfield Township, about one-half mile from the Indiana and Western Electric Road, is an extensive series of swampy depressions, locally known as the "old iron ore-bed swamps". Four years ago, 100 to 150 acres of these swampy lands were drained and are now in part under cultivation. The peat is black and well decomposed; it averages from one to two feet in thickness and is underlaid with sand.

It is reported that the tooth of a mastodon was obtained from one of the marshes but it was impossible to ascertain the precise locality.

The "Barrens," the marshy prairies, aspen swamps,—all stages of a succession of plant associations—constituted a body of land that only recently was supposed to be almost worthless. Through drainage and cultivation it has become highly productive and valuable. The portion of "unproductive" marshes now lies along the lake and bay, principally in Jerusalem Township, and consists of approximately 6,000 acres of marshy land. Improved methods of drainage and cultivation have made small tracts of even this exceedingly fertile.

MAHONING COUNTY

Topographically this county is a part of the northeastern highland. Its surface consists of an alternation of broad valleys and excavations, separated by rounded hills and table-land with gentle slopes.

BEAVER TOWNSHIP

Snyder Bog.—This tamarack bog is about one and one-half miles east of Snyder in sections 24, 25 and 36. It is favorably located on the Youngstown and Southern Electric Railway. The location and the area are shown on the Columbiana sheet of the United States Topographic Survey (Fig. 6). The bog now covers about 500 acres, but it is said that fires have destroyed other portions which formerly extended for a great distance northeast.

The northern end of the bog is largely a cattail marsh. The plants are very dense and more abundant than any of the secondary species listed below. The peat has a decided sulphurous odor and contains over 12 per cent. of ash. Its thickness ranges from 2 to 5 feet in the deeper parts.

The following species were observed as a secondary layer, growing among the cattails: Arrow-leaved tearthumb (*Polygonum sagittatum*), bur reed (*Sparganium*

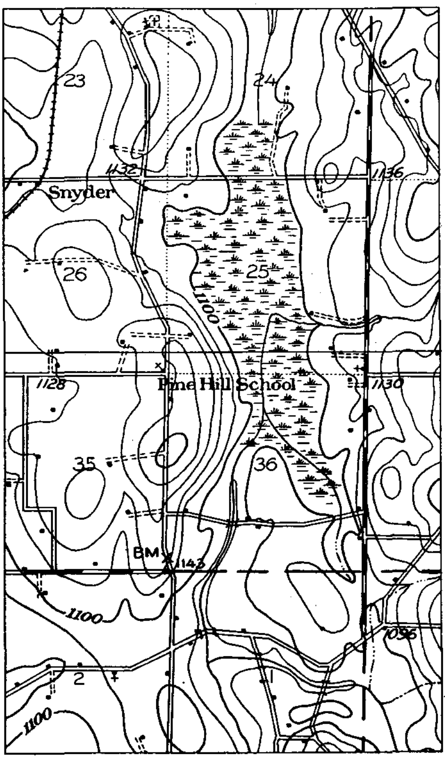


Fig. 6.—Map of Snyder Bog in Mahoning County.
Scale, 1 inch = 1 mile (2.5 cm. = 1.6 km.).

eurycarpum), arrow-head (*Sagittaria latifolia*), water dock (*Rumex britannica*), shield fern (*Aspidium* = *Dryopteris thelypteris*), touch-me-not (*Impatiens biflora*) and milkweed (*Asclepias tuberosa*).

The southern portion of the bog is densely covered with trees. Tamarack is the dominant species, and red maple thrives near the outer border. The shrubby undergrowth consists of alders (*Alnus incana, A. rugosa*), poison sumach (*Rhus vernix*), high-bush blueberry (*Vaccinium corymbosum*), winterberry (*Ilex verticillata*), silky willow (*Salix sericea*), chokeberry (*Pyrus melanocarpa* = *Aronia nigra*), wild black cherry (*Prunus serotina*), arrowwood (*Viburnum dentatum*) and others. Several of these form almost impenetrable thickets, especially near the edges of the bog and at a point almost directly south of the Pine Hill school in section 36. Where the stand of the trees and shrubs is dense the ground-cover is principally one of tamarack needles, leaves of shrubs and a few seedlings. In the more open areas the following species are fairly numerous—flowering ferns (*Osmunda regalis, O. cinna-*

momea), chain fern (*Woodwardia virginica*), manna grass (*Glyceria canadensis*), sedges (*Carex tribuloides, C. vulpinoidea*), common rush (*Juncus effusus*), occasionally a silky willow (*Salix sericea*) and cushions of sphagnum mosses with prostrate bramble (*Rubus hispidus*), violets and mayflower (*Maianthemum = Unifolium canadense*).

A number of testborings were made, all of which indicate a well decomposed, brownish peat at the 3-foot level, a fibrous, blackish peat at the 5-foot level and a finely fibrous, brown peat from this to the 9-foot level. Below this the debris is more coarsely fibrous, but again becomes a well decomposed and reddish brown peat as the 15-foot level is approached. Near the 17-foot level the debris is slightly charged with clay which increases in proportion a few inches below. The chemical composition of the mixed sample is as follows:

Analysis No. 50

		Air-dried.	Moisture-free.
Moisture		10.01	-------
Volatile combustible		55.76	61.97
Fixed carbon		26.14	29.05
Ash		8.09	8.98
Nitrogen		2.39	2.66
Sulphur		0.28	0.31
Calorific value	Calories	4370.00	4854.00
	B. t. u	7866.00	8737.00

The relatively small percentage of ash and the fairly high thermal value are only two of the good qualities of this peat. The well decomposed condition of the debris, which permits its use in various ways, and especially its agricultural possibilities, are no less important excellencies which this deposit possesses.

GOSHEN TOWNSHIP

Garfield Bog.—The bog is one-half mile west of Garfield and easily reached by means of the Stark Electric Railway. There are approximately 200 acres in sections 30 and 31. The area and outline are shown on the Lisbon quadrangle of the United States Geological Survey. The deposit is not very extensive and the peat is rather impure, probably on account of the silt and clay which washed in from the adjoining hilly country. Cattail (*Typha latifolia*), bur reed (*Sparganium simplex*), and impenetrable thickets of spirea, willows, buttonbush and alders make up the vegetation in the areas not used for pasture. A part of the tract is under cultivation. A few isolated specimens of tamarack were found in the deciduous woods along the eastern border of the deposit. No analyses were made of the peat samples.

GREEN TOWNSHIP

New Albany Marsh.—The marsh is in sections 9 and 16 of Green Township about one and one-half miles northeast of New Albany.

The area is rather extensive, approximating 400 acres, as may be seen by reference to the Lisbon quadrangle of the United States Geological Survey. High hills surround the swamp along its eastern border. Material washed in from these banks and the silt brought in by the creek passing through the peat deposit make it of little value for purely commercial purposes.

Berlin and Canfield townships have small deposits, but they were not visited.

MEDINA COUNTY

This county is situated along the northeastern highland which divides the water between the Ohio River and the Mississippi, and Lake Erie and the St. Lawrence. The eastern half of the county is quite rolling and the soil is loamy. The western half is much more level, the soil being largely clay. Most of the bogs with the great marshes occur on land much lower than any other along the divide and yet many of them are drained in both directions. The peat deposits are of various sizes and shapes. The larger tracts are ancient finger lakes and cover several hundred acres, as, for example, those near Seville in Guilford Township, while the smaller ones approximate three to four acres. All have been drained and are under cultivation.

HARRISVILLE TOWNSHIP

Garden Isle.—This deposit was originally an extensive shallow lake which was completely filled with the debris from the vegetation growing upon it. It is today an extensive peat prairie, dry and firm enough to support any agricultural crop. It is said that trees, vines, shrubs and ferns formerly grew in dense clumps and were characteristic of the vegetation in neighboring peat deposits. However, all of the area—about 2,000 acres—has been plowed and is now under cultivation (Plate VIII, B.).

The deposit lies south of Lodi along the Millersburg branch of the Baltimore and Ohio Railway. The topography and location are shown on the Wellington sheet of the United States Geological Survey. Test-borings were made at various places and showed a deposit of peat not over three feet in depth over the greater part of the area. The underlying clay is heavy and grayish in color. The surface peat is dark-brown and well decomposed. At a depth of three feet and extending down to the 5-foot level the material has a grayish brown color, is slightly fibrous and contains woody fragments, and seeds of sedges and grasses. The digging of ditches has revealed shell marl, but not in large quantities.

A composite sample gives the following chemical analysis; the fertilizer constituents are given in table 32:

Analysis No. 70

	Air-dried.	Moisture-free.
Moisture	7.53	-------
Volatile matter	51.43	55.60
Fixed carbon	24.66	26.69
Ash	16.38	17.71
Nitrogen	2.38	2.58
Sulphur	0.63	0.69
Iron	1.24	1.34
Calorific value { Calories	4195.00	4538.00
Calorific value { B. t. u	7551.00	8168.00

While the great body of the prairie is exceedingly fertile, there is a remarkable exception in a small tract at a place two miles southeast of Lodi and one and one-sixth miles northeast of the office building of the Horr-Warner Company. The soil is a peat which, in its physical texture, presents nothing to the eye that serves to distinguish it from the productive area surrounding it. It is under cultivation, but the crops do not grow and the plants are dwarfed, the yield usually being a light growth of weeds. Testborings show at the 3-foot level a coarsely fibrous, reddish brown peat which contains small quantities of pyrite and darkens rapidly upon exposure to air. A peculiar pungent sulphurous odor is very characteristic of the peat from this depth. At the 5-foot level the peat is of a darker color shading into a black, well decomposed debris. At the 7-foot level the peat is again reddish brown, very compact but slightly fibrous, with seeds of water plants. Near the 8-foot level the peat is grayish in color and contains fragments of wood. The debris is underlaid by a sandy clay. The peat from this section gives the following chemical analysis:

Analysis No. 71

	Air-dried.	Moisture-free.
Moisture	7.67	-------
Volatile matter	52.56	56.93
Fixed carbon	19.35	20.93
Ash	20.42	22.14
Nitrogen	2.36	2.55
Sulphur	4.21	4.57
Iron	2.01	2.16
Calorific value { Calories	3659.00	3962.00
Calorific value { B. t. u	6586.00	7132.00

The fertilizer constituents are given in table 32. The difference between this sample of peat and that taken in the immediate vicinity of the sterile tract is one which is best expressed in terms of soil processes. The physical texture of the peat, as revealed by the testborings, clearly shows that this portion of the ancient lake, because of its greater depth, remained for a long time open water. Prior to its cultivation, it had just grown over with a coarsely fibered mat of grasses and sedges.

It is now a well known fact that microörganisms in the soil aid in the partial disintegration of a peat mat. During an early stage the organic decomposition products are mostly injurious to crops and agricultural plants, but in the later stages of the process the peat soil contains nitrogenous and other organic substances which can be assimilated readily by higher green plants. The soil has as elsewhere every element of fertility, and there can be little doubt that the deleterious reducing substances of the early decomposition phase are the sole cause of the sterility encountered. Laboratory methods have shown the presence of the organisms, and the fact that the quantity of sulphur and iron is so small in the one sample, and so excessively large in the other further indicates that the conversion of sulphur compounds to hydrogen sulphide gas is still going on in the smaller peat tract. A discussion of the soil process is given in another chapter (p. 343 ff).

A deposit of peat of about 600 acres occurs in the central part of Granger Township. The area and location are indicated on the Akron topographic sheet. The depth and character of the peat were not tested.

The extensive peat prairie, north and south of Seville in Guilford Township, is almost wholly under cultivation. No detailed examination was made of the character and the depth of the deposit. It represents an ancient finger lake approximately twenty miles in length, extending along the valley of the Chippewa River from Medina southward past Seville almost to Canal Fulton in Stark County. Chippewa and Luna lakes are remnants of this lake. The valley has only restricted areas of peaty soil, much of which has an admixture of sandy clay. The survey made by the United States Bureau of Soils indicates 5,760 acres of peat for the Wooster area varying in depth from 2 to 15 feet.[1]

MERCER COUNTY

The topography of this county is that of a continuous plain with the natural slope toward the north. Three successive ridges or belts of glacial drift cross the county and mark the periodic resting places of the glacier in its retreat. North of St. Mary's ridge the surface is flat and uniformly clayey. In Black Creek Township, sections 19 and 20, is a small shallow peat deposit, less than 300 acres in extent, which is known locally as Duck Creek Prairie. Much of the peat cover has been burned off from time to time so that the surface is now largely a black alluvial-like deposit.

The portion of the county between the Wabash River and St. Mary's ridge is characterized by several prairie-like tracts and marshes. The soil seldom shows any gravel and has all the features of the noted Black Swamp of which it undoubtedly is a portion.

[1]Caine, T. A., and Lyman, W. S., Soil Survey of the Wooster Area; Field Operations of the Bureau of Soils, 1904, pp. 543-564.

GRANVILLE TOWNSHIP

The portion of the county south of the St. John's ridge has a noticeably rolling contour. It forms part of the highland known as the divide, but until recently contained several large uncultivated cranberry marshes. The area is even now subject to inundation in spring time. The larger one of the marshes which is in Granville Township forms an extended low basin of about a thousand acres, situated between Burkettsville (Gilbert Station on the Cincinnati Northern Railway) and the village of Cranberry Prairie. The peat is a rich, black deposit, fairly well drained and wholly under cultivation.

Several testborings were made on the land owned by J. Muhlenkamp. The surface peat, which shows signs of repeated fires, is dark-brown, almost black, in color; it is finely fibrous and becomes a matted turf toward the 3-foot level. At the 5-foot level the material is a black muck which rests on brownish, fibrous peat. At the depth of 7 feet the debris is olive green in color with an admixture of charred peat; the deposit rests on grayish clay which in some places is quite marly.

The fertilizer value is indicated in table 32; the proximate analysis of the composite sample is as follows:

Analysis No. 81

		Air-dried.	Moisture-free.
Moisture		8.72	-------
Volatile matter		58.89	64.51
Fixed carbon		25.66	28.12
Ash		6.73	7.37
Nitrogen		2.53	2.77
Sulphur		0.47	0.51
Calorific value	Calories	4522.00	4953.00
	B. t. u	8140.00	8915.00

A number of testborings were made on land owned by G. Vandenbush, showing a physical texture of the peat very much like that just described. Much of the material has been burned off so that the thickness of the deposit averages only about 4 feet. The chemical analysis is as follows:

Analysis No. 80

		Air-dried.	Moisture-free.
Moisture		9.28	-------
Volatile matter		50.62	55.79
Fixed carbon		23.37	25.77
Ash		16.73	18.44
Nitrogen		2.98	3.19
Sulphur		1.25	1.38
Iron		0.92	1.02
Calorific value	Calories	3922.00	4323.00
	B. t. u	7060.00	7781.00

It was thought possible that in some places the deposit might be of greater thickness than found thus far. Testborings were made, therefore, at various places in sections 25, 26 and 35, but almost everywhere it seemed that before long the plow would extend through the well humified peat and penetrate the underlying clay. Fire has undoubtedly removed the greater part of the accumulation. A mixed sample of the testborings gave the following result:

Analysis No. 79

		Air-dried.	Moisture-free.
Moisture		10.23	-------
Volatile matter		50.02	55.72
Fixed carbon		21.98	24.49
Ash		17.77	19.79
Nitrogen		2.67	2.97
Sulphur		0.98	1.10
Iron		0.75	0.84
Calorific value	Calories	3871.00	4312.00
	B. t. u	6968.00	7762.00

The quality of this peat warrants agricultural exploitation only.

MIAMI COUNTY

The general slope of this county is from north to south, with two subordinate systems of drainage which carry the water across the entire county. East of the Miami River the surface is rolling; gravelly ridges are abundant. The free drainage prevented an accumulation of peat on the low lands. On the other hand, the wide scope of land on the watershed between the Miami and Stillwater rivers is flat and poorly drained. Years ago numerous marshes abounded which were known locally as "shaking prairies." The peat deposits of the county are almost wholly under cultivation. The soil is structureless, compact and black in color. It has a per cent. of mineral matter too high for profitable commercial utilization. Tillage, burning, and constant cultivation have transformed the peat more or less completely into humus. Mr. Hussey in his report of the Geology of Miami County[1] gives the following interesting account: "Rough sedge-grasses, mosses and kindred vegetation flourished in this region, growing and perishing successively, until several feet of deep, black soil had been accumulated. At a certain time, trees suitable to a wet region, such as elms, soft maple, and shrubs such as buttonbush, and finally, bur-oak and ash, began to grow. The vegetable material perishing, underwent a process of decay, or rather, a process of preservation. The substance of the vegetation broke down into a number of compounds, which, situated as they are in moisture, do not undergo further decay. This material was arrested in a stage of decomposition different from that of the drier substances on the rolling driftland east of the Miami River. In the case of much of the vegetation east of the river, it passed back by complete decomposition into

[1]Geol. Surv. Ohio, Vol. III, 1878, pp. 468-481.

"thin air," into invisible gases, and left no trace behind. A certain other portion was arrested in the process of decay, and forms the mould, which, with the clay commingled, constitutes the soil. On this side flourish the oaks, beeches, walnuts, sugar maple, with an undergrowth of dogwood, redbud, haw, pawpaw, with a peculiar vegetable growth which sprung up and perished annually. The most of the growths of the east side differed entirely from those in the swampy district of a former day, where the deep, fibrous, black soil is found west of the Miami River. The moisture retained on the surface has a two-fold influence—one to favor a vegetation, as I have said, of a peculiar class, the other to prevent its decomposition, in fact, to preserve it. The two classes of soils differ in four respects: (1) In the quantity of vegetable substances; (2) in the condition they are in as regards the extent of decay which they have undergone; (3) in the character of the vegetable substances which make up the material, and (4) in the different proportion of clay they contain—that on the east being composed largely of clay, while very little clay is found in the swamp soil."

MONTGOMERY COUNTY

Peat deposits that existed at one period over a large part of the southwestern and southern portion of the State, either in independent basins or in more or less continuous sheets, have been almost completely removed by the intense denudation which the region subsequently underwent. A few small deposits still remain, the largest being the one which has lately been found one mile east of Germantown, in section 18 of German Township. The topographic features of the area are indicated on the Miamisburg topographic sheet of the United States Geological Survey. It is a fossil peat bed, exposed in the channel of Twin Creek, a tributary of the Miami River. The river valley seems to have been deeper formerly than it is at present for it is partly filled with drift, the stream no longer flowing over the bed rock. In fact the absolute depth of many of the Ohio River valleys has been diminished by the later glacial deposits.

GERMAN TOWNSHIP

A deep deposit of a sandy clay, blackened by organic matter to a depth of several feet from the former soil surface, holds a nearly horizontal position and shows it to have been marshy in its general condition. There are indications that the marsh had a considerable extent to the northward and eastward and that the peat bed represents the deeper portion of an extensive water basin. A deposit of stratified clay and gravel from about 80 to 100 feet in thickness covers the peat bed. The constant undermining action of the stream has kept the drift along the east bank nearly vertical. Beneath this heavy deposit the exposed peat is found varying in thickness from 1 to 4 feet, but an early geological report[1] gives the thickness as ranging from 12 to 20 feet.

The uppermost layers of the deposit contain undecomposed sphagnum mosses which are covered with a fine, silty blue clay. The lower portions are at first slightly fibrous, and then grade into a well decomposed, very compact peat which contains woody fragments. In color the debris varies from brown to nearly blackish brown as the bottom of the deposit is approached. The peat rests on a bed of fine sand several feet in thickness, underlaid by clay and gravel. It is said that at the southern margin of the deposit a large amount of timber was encountered, "trunks, roots, branches and twigs, much of which has been flattened by the pressure of the 80 feet of clay and gravel that overlies it. Branches that were originally two inches in diameter now afford lenticular sections with no more than one-fourth of an inch for the shorter axis, while many of the smaller stems have been compressed into ribbons. The berries of the cedar (*Juniperus virginiana*) are abundant in the upper layers of the peat. At a point one-half mile higher up the stream, trunks of cedar nearly two feet in diameter have been taken from beneath these same drift beds and turned to account for fencing posts."

"The wood is in great part coniferous, but not exclusively so; for according to the testimony of intelligent and observing practical men, who deem themselves entirely competent to give a judgment in the case, ash, hickory, sycamore, together with wild grape vines and beech leaves, have been found covered with drift deposits."

"Two mastodon tusks, each measuring eight feet in length, were taken in the spring of 1870, from the northern part of the same drift bed to which the peat belongs and at about the same level."

The following is the chemical analysis of a mixed sample of fossil peat from this locality:

Analysis No. 84

		Air-dried.	Moisture-free.
Moisture		7.02	-------
Volatile matter		24.95	26.83
Fixed carbon		5.77	6.20
Ash		62.26	66.97
Nitrogen		0.86	0.93
Sulphur		0.51	0.55
Calorific value	Calories	1505.00	1619.00
	B. t. u	2709.00	2914.00

OTTAWA COUNTY

The surface of this county is elevated but little above Lake Erie, and hence a large part of the shore and the flood plain of the streams is marshland. There are approximately 7,500 acres of marsh, the location

[1]Geol. Surv. Ohio, Rept. of Progress, Report on Geology of MontgomeryCounty, 1869, pt. 3, pp. 165-167.

of which is shown on the Oak Harbor, Fremont and Put-in-Bay topographic sheets of the United States Geological Survey. As in Erie County, the accumulation of vegetable debris has been continuous with the rise of the water in the lake over a long period of time. The vegetation is one principally of bulrushes, reed grasses, cattail, bur-reed and others.

With the aid of jetties, piers or crib-work the marshland could be easily relieved of its surplus of standing water and brought into an arable condition.

Sandusky County has in Riley Township marshland of a similar character. The area, approximately 3,500 acres, is shown on the Fremont topographic sheet.

PAULDING COUNTY

This county, in its entire area is within the "Black Swamp" region. The topographic features are those of a broad, level plain. There are no peat basins, bogs or marshes. The soil is a retentive clay which received its level surface from the action of the ancient glacial lake that formerly covered this and neighboring counties. The area in this county remained submerged the longest, and when the surface appeared above water again the general character of the surrounding vegetation consisted of deciduous trees and shrubs. Oak, beech, elm and walnut, sugar maple, dogwood, pawpaw, redbud and others invaded the new territory. The vegetable mold from the leaf-fall and from decaying trunks covered the clay. Burrowing animals, crayfish, insect larvæ and earthworms which abounded on the undrained plain, brought the lower soil to the surface and thus mingled the upper and lower portions to a depth of several feet, until today the incorporation of the organic matter with the clay soil has imparted to it a black color and a remarkable fertility.

PORTAGE COUNTY

This county, in common with many others that contain peat, is located on the watershed which separates the streams flowing into Lake Erie from the tributaries of the Ohio River. The surface is formed mainly by a sheet of clay with occasional heavy beds of gravel which form well defined swells and rounded hills on the northern and southern slope of the watershed. There are numerous lakes on the watershed and in the basins inclosed by the gravel hills and ridges which are usually supplied by subterannean springs. Long ago many of these were filled by vegetation and now exist as peat prairies, while others show various phases of the filling-in process.

There are several extensive peat deposits of excellent quality in the county, and many smaller ones known locally as cranberry marshes, huckleberry bogs, blueberry swamps and tamarack bogs. They occur in nearly every township. The fact that Portage County peat ranks high in quality and in units of thermal value seems to have been well known, since as early as 1869 a factory was established near Ravenna for the cutting of peat and putting it into a commercial form. Operations were suspended when the buildings were destroyed by fire in 1906. The peat in many bogs is frequently underlaid by *Chara* and shell marl and the accumulation of the latter in several localities is large enough for use with profit.

ATWATER TOWNSHIP

The Atwater Bog.—This bog is about one-half mile northeast of Atwater Center. It extends northward for two miles and varies in width, averaging about one-fourth of a mile. Its form and dimensions, approximating 400 acres, are shown on the Ravenna topographic sheet of the United States Geological Survey. Deer and Willow creeks have their source in the bog, much of which has been burned over repeatedly.

Tamarack groves occur scattered here and there with an undergrowth of chokeberry (*Pyrus melanocarpa* = *Aronia nigra*), arrowwood (*Viburnum dentatum*, *V. nudum*), winterberry (*Ilex verticillata*), mountain holly (*Nemopanthus* = *Illiciodes mucronata*), blueberries (*Vaccinium corymbosum*, *V. pennsylvanicum*), stemless lady's slipper (*Cypripedium acaule*), wood fern (*Aspidium* = *Dryopteris cristata*), and others. Cassandra or leather leaf (*Chamaedaphne calyculata*) is not uncommon in more open areas and with it are found often sphagnum and polytrichum mosses, the prostrate bramble (*Rubus hispidus*), cranberry vines, sedges (*Carex trisperma*), and several of the larger ferns such as *Osmunda regalis* and *O. cinnamomea*. Of the deciduous trees, red maple and black gum (*Nyssa sylvatica*) were frequently noted.

The southern border of the bog is surrounded by an exceedingly dense and impassable thicket, consisting of *Viburnum dentatum* and *Aronia species*. Adjoining them toward the outer edge of the marsh are areas densely covered with briar (*Rubus sp.*). This condition is attributed to repeated fires.

The testborings indicate that the deposit is shallow. The debris is a reddish brown, coarsely fibrous peat, very compact and extending to a depth of 3 feet. It is underlaid by a blackish silty, fluid peat, resting at the 4-foot level on a grayish blue clay. A number of testborings were made at various places and the composite sample gives the following chemical analysis.

Analysis No. 55

	Air-dried.	Moisture-free.
Moisture	8.65	-------
Volatile matter	62.12	68.01
Fixed carbon	23.68	25.91
Ash	5.55	6.08
Nitrogen	2.74	3.01
Sulphur	0.25	0.26
Calorific value { Calories	4794.00	5246.00
Calorific value { B. t. u	8629.00	9443.00

AURORA TOWNSHIP

Solon Bog.—In the extreme northwest corner of the township are approximately 70 acres of peat land, the location and area of which are shown on the Chagrin Falls topographic sheet of the United States Geological Survey (Fig. 2). The deposit extends into the adjoining counties. The vegetation covering the peat area consists principally of grasses and sedges, cattails, ferns (*Aspidium=Dryopteris thelypteris, Onoclea sensibilis*), sphagnum mosses and occasionally willow thickets. The material, which is well decomposed and blackish near the surface, brown and woody to a depth of 11 feet, greenish and laminated at the 12-foot level, rests upon clay. Signs of fires are not uncommon. The samples taken for analysis were lost during transportation.

Aurora Pond.—This body of water, which is about one mile south of the deposit mentioned above, has a border of shallow peat, the exact limits of which probably correspond to that of the 1,000-foot contour line indicated on the Chagrin Falls topographic sheet (Fig. 2). An almost concentric border of water lilies, 10 to 25 feet in width, is the most noticeable feature. Pickerel weed (*Pontederia cordata*) is found well mixed at various places with cattail. Along the western portion of Aurora Pond the swamp loose-strife, with buttonbush and swamp rose, forms the shore vegetation succeeding the water lilies and leading into a bog meadow. The most conspicuous representatives of the meadow are wool grass (*Scirpus cyperinus*), St. John's wort (*Hypericum sp.*), several ferns (*Aspidium=Dryopteris thelypteris, Osmunda cinnamomea, Onoclea sensibilis*), species of *Sagittaria* and occasionally a clump of willows or of aspen. Changes in the water level and fire have undoubtedly caused the disjointed distribution of the plants, for at other places their arrangement and distribution correspond more nearly to the genetically related successions spoken of in another chapter. On the southwestern side the meadow adjoins a heavily wooded area. Tamarack, hemlock and white pine were until recently the dominant trees. Today they occur only scattered as members of a bog forest which has for its principal species red maple, black ash, elm and some birch (*Betula lutea*), with an undergrowth of alders, dogwood, arrowwood (*Viburnum dentatum*) chokeberry, mountain holly, lizard's tail, sphagnum mosses and several others.

A number of testborings were made at various places. The peat is not of great thickness; it averages 4 feet and throughout this depth is relatively impure. The chemical analysis of mixed sample No. 48 for this locality has not been received, the material having been lost during transportation.

BRIMFIELD TOWNSHIP

Brimfield Bog. — Most of the deposit is forested with hardwood shrubs and trees. The area and locality are shown on the Kent topographic sheet of the United States Geological Survey (Fig. 7). The bog is a depression in the drift and averages 12 feet of peat. The latter is resting on a cream-colored marl of great purity, varying in thickness from 2 to 4 feet. The deposit extends northwest and southwest and is about one and one-half miles east of the Wheeling and Lake Erie Railroad. The total area of the bog, which is not considerable, approximates about 200 acres. A creek tributary to the Cuyahoga River has its source near the central portion of the bog.

A number of testborings were made at various places. On the land owned by Mrs. B. Bauman, the deposit southeast of the residence is of

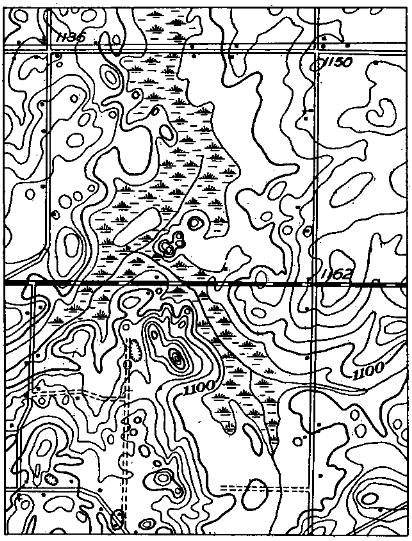


Fig. F.—Map of Brimfield Bog in Portage County.
Scale, 1 inch =1 mile (2.5 cm.=1.6 km.)

excellent quality. A line of testborings was run in an east and west direction across the central portion of the bog beginning near the residence. The readings are as follows:

On the west side near the border of the bog is a blackish brown, well decomposed peat to a depth of 3 feet, underlaid by peaty clay resting on sand. About 200 feet farther east the peat is of similar texture but slightly more fibrous to a depth of 8 feet; below this is a plastic, non-fibrous debris underlaid by 5 feet of cream-colored, fine-grained marl with shells, resting at the 15-foot level upon a grayish blue clay. At a point approximately in the center of the deposit, and 350 feet east from the last mentioned boring, the peat is similar in texture to a depth of 16 feet. Below this level a greenish brown, fine-grained peat filling was encountered. Near the eastern border of the bog the material is also well decomposed but rather fluid at the 5-foot level, compact and dark-brown near the 9-foot level, slightly woody at the 11-foot level and coarsely fibrous to the 17-foot level.

The vegetation covering the deposit consists in part of tamarack, much of which shows signs of severe fires. There are occasional trees of yellow birch (*Betula lutea*), ash (*Fraxinus nigra*), oaks (*Quercus palustris, Q. alba, Q. platanoides* [?]) and elm (*Ulmus fulva*). Among the shrubs and smaller plants were noted alders (*Alnus incana, A. rugosa*), arrowwood (*Viburnum nudum*), chokeberry, mountain holly, highbush blueberry, willow (*Salix sericea*), buttonbush (*Cephalanthus occidentalis*), juneberry (*Amelanchier canadensis*), dogwood (*Cornus candidissima, C. stolonifera*), low blueberry (*Vaccinium pennsylvanicum*), black huckleberry (*Gaylussacia resinosa=baccata*), tickseed (*Bidens trichosperma*), partridge berry (*Mitchella repens*), several ferns (*Osmunda cinnamomea, O. regalis, Onoclea sensibilis*) and others.

The land is owned by Mrs. Bauman. The composite peat sample No. 52 from the maple-ash-elm association gives the following chemical analysis:

Analysis No. 52

		Air-dried.	Moisture-free.
Moisture		11.25	-------
Volatile matter		51.15	57.64
Fixed carbon		27.65	31.19
Ash		9.95	11.17
Nitrogen		2.08	2.33
Sulphur		0.70	0.74
Calorific value	Calories	4220.00	4758.00
	B. t. u	7596.00	8564.00

It shows a moderate percentage of ash and a relatively high thermal value.

Two deposits, one of which is a mile south of Kent and the other in the southeastern corner of the township, were not tested. They are said to be of considerable thickness and of good quality.

Cranberry Marsh.—This is a typical cranberry bog covering an almost circular area of about two acres; it is located in the drift, about one-half mile east of Brimfield Station on the farm of Frank Lautenslager. Sphagnum mosses and cranberry vines are the dominant plants with several sedges and grasses and a few scattered thickets of high-bush blueberry (*Vaccinium corymbosum*), alders (*Alnus incana*), chokeberry (*Pyrus=Aronia arbutifolia*), winterberry and low-bush blueberry *Vaccinium vacillans*). Testborings indicate at the 3-foot level a dark-brown, well decomposed peat, slightly fibrous and reddish brown toward the 5-foot level, greenish in color near the 7-foot level and resting on a very compact blue clay at the 9-foot level. Nearer the margin (with *Juncus effusus* dominant) the peat is more coarsely fibrous. The analysis of a sample from this bog is as follows:

Analysis No. 53

		Air-dried.	Moisture-free.
Moisture		8.41	-------
Volatile matter		52.75	57.58
Fixed carbon		25.30	27.64
Ash		13.54	14.78
Nitrogen		1.48	1.62
Sulphur		0.23	0.25
Calorific value	Calories	4581.00	4998.00
	B. t. u	8246.00	8996.00

FRANKLIN TOWNSHIP

"Eckert Bog."—One of the best illustrations of the final stages of bogs is found in a steep-sided depression in Franklin Township about 5 miles northeast of Kent. The bog is north of Brady Lake near the Cuyahoga River and about one mile southwest of the northeastern corner of the township. The area is approximately 30 acres. In the middle of the bog is an irregular elliptical area, somewhat higher and slightly wetter than the general surface, which represents the part of the open water last covered. Upon this wetter portion the principal plants are cassandra with relatively few specimens of bog rosemary (*Andromeda polifolia=glaucophylla*). Black huckleberry is another heath rather abundant in the drier portions of the bog. Cranberry vines and sphagnum mosses cover most of the surface, the latter plant often in dense conical masses 3 or 4 feet above the ground water level. Seedlings and young trees of tamarack occur scattered over this well marked central portion. With them in a zone more shoreward are several big shrubs such as winterberry, mountain holly, chokeberry, high-bush blueberry and arrowwood beneath the older tamaracks. Testborings indicate a dark, reddish brown, slightly fibrous peat to a depth of 11 feet. Beneath this level the peat is woody, and fallen timber is frequently encountered. From the 13-foot to the 18-foot level the peat is more coarsely fibrous. The bottom was not reached.

The growth of tamarack surrounding the central portion of the bog forms a well marked zone. It is a dense, almost pure stand with an occasional yellow birch (*Betula lutea*). The undergrowth is largely one of the shrubs above mentioned The ground cover consists of several species of orchids and ferns, wintergreen, prostrate bramble, mayflower and others. The testborings indicate a depth and a texture of peat in all respects similar to that of the more central portion. The bottom was not reached.

Around the tamarack grove and to the shoreward border of the depression a number of deciduous trees are dominant. Red maple is most abundant, swamp oak (*Quercus palustris*), birch (*Betula lutea*) and wild cherry with white rod (*Viburnum cassinoides*) are occasionally found. The undergrowth is principally one of ferns; the bog shrubs are rarely of a uniform height or of vigorous growth. Testborings indicate 10 feet of peat and the underlying material of drift.

Analysis No. 56 represents peat from several testborings in the tamarack association. It shows a very high thermal value and but very little ash.

Analysis No. 56

		Air-dried.	Moisture-free.
Moisture		9.36	-------
Volatile matter		60.50	66.73
Fixed carbon		26.84	29.62
Ash		3.30	3.65
Nitrogen		1.51	1.66
Sulphur		0.20	0.21
Calorific value	Calories	4903.00	5409.00
	B. t. u	8825.00	9736.00

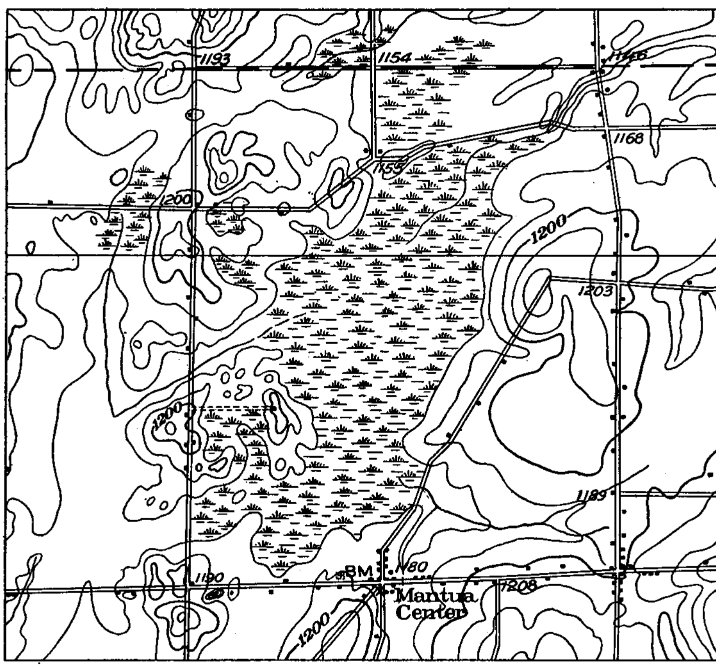


Fig. 8.—Map showing area and location of Mantua Bog in Portage County. Scale, 1 inch = 1 mile (2.5 cm. = 1.6 km.).

The deposits in the southwest corner of the township and the one about a mile northeast of Kent were not tested. The peat area aggregates about 300 acres.

MANTUA TOWNSHIP

"Mantua Bog."—This bog is of a still more mature type than the one just described. The location and area are shown on the Chagrin

Falls and Garrettsville topographic sheets of the United States Geological Survey (Fig. 8). Red maple, black ash, wild cherry and elms are the dominant trees.

A list of the undergrowth includes the following species: Chokeberry, mountain holly and winterberry, azalea (*Rhodendron viscosum*), high-bush blueberry, wild black cherry, arrowwood (*Viburnum lentago, V. dentatum, V. nudum, V. cassinoides*), dwarf huckleberry (*Gaylussacia dumosa*), buckthorn (*Rhamnus alnifolia*), wild currant (*Ribes floridum*), the flowering ferns, mayflower, star flower (*Trientalis americana*), golden thread (*Coptis trifolia*), sedges (*Carex leptalea*) and patches of sphagnum mosses. Tamarack and yellow birch (*Betula lutea*) have suffered severely from fires and the surface of the bog in several places has been lowered from the same cause. In the clearings, cattail, nettle, touch-me-not, fire weed (*Epilobium coloratum*), spindle tree (*Evonymus obovatus*), evening primrose (*Oenothera biennis*), virgin's bower (*Clematis virginiana*), shield fern, spiraea and others are present.

The thickness of peat varies from a few inches along the border to 8 feet in the deeper portions. It is of very good quality except that it contains sandy layers, probably representing seasons of floods. The samples of peat from the portion of the bog covered with deciduous trees give the following proximate analysis (for fertilizer value see table 32):

Analysis No. 47

		Air-dried.	Moisture-free.
Moisture		10.40	-------
Volatile matter		50.48	56.33
Fixed carbon		23.42	26.16
Ash		15.70	17.51
Nitrogen		2.20	2.46
Sulphur		0.77	0.86
Calorific value	Calories	4076.00	4550.00
	B. t. u	7337.00	8190.00

Randolph, Nelson, Suffield, Shalersville and Streetsboro townships contain several deposits, approximately 2,000 acres in all, the area and locality of which are indicated on the Kent and Chagrin Falls topographic sheets. Except the bogs near Moran, the testborings which were made at various points failed to show more than 4 feet of peat. The samples were almost half mineral matter and the deposits are, therefore, unsuitable for fuel purposes. This is well shown in the following analysis of sample No. 46 from a heavily forested peat deposit 4½ miles northeast of Garrettsville and 1¼ miles east of Nelson.

Analysis No. 46

		Air-dried.	Moisture-free.
Moisture		9.12	-------
Volatile matter		36.68	40.37
Fixed carbon		16.51	18.16
Ash		37.69	41.47
Nitrogen		1.56	1.72
Sulphur		0.39	0.43
Calorific value	Calories	2586.00	2845.00
	B. t. u	4655.00	5121.00

RAVENNA TOWNSHIP

The bogs near the city limits of Ravenna are quite interesting and in some respects unique. They are among the first deposits which were explored in Ohio for commercial purposes, and are said to have given much trouble along the line of the Pennsylvania Railroad. On the east side of this road, about one mile south of the city limits, a cass andra bog is still in fairly good condition, although fires occur here almost annually. The list of plants includes, in addition to the dominant growth of cassandra (*Chamaedaphne calyculata*), thickets of chokeberry, winterberry, mountain holly, high-bush blueberry, several arrowwoods, alders, huckleberry, ferns and others. The weight of the material used for filling in the embankment has broken the mat and caused its displacement. Its rise in several places amounts to from 3 to 6 feet. The peat was examined at various points and testborings indicate 17 feet of a well decomposed, slightly fibrous variety. The bottom was not reached with the available lengths of the sounding instrument.

On the west side of the embankment the peat deposit is more extensive. Fire sweeps periodically over the area, and hence the growth of trees, shrubs and herbs is dense only along the shores of the small lake which represents the part of the original basin still uncovered.

The vegetation around the lake and shoreward to the border of the depression, has much in common with that of the other lakes along the divide. The open water is bordered by swamp loose-strife; shoreward of this is a meadow-like association consisting of shield fern, St. John's wort, sphagnum mosses, bur marigold, water hemlock, golden rod (*Solidago rugosa*) and others. A narrow zone of alders, white spirea, wild rose with sphagnum in abundance, follows the meadow. Testborings indicate a dark-brown, well decomposed peat, containing a quantity of fallen timber. Below the 13-foot level the peat is blackish, non-fibrous, well decayed and rather plastic. The bottom was not reached.

The narrow zone of alders is followed by a heath association similar in character to that on the east side of the embankment. Cassandra is relatively abundant and occurs with poison sumach, several arrowwoods, buttonbush, spiræa (*Spiraea tomentosa*), black huckleberry, ferns, sphagnum mosses and others. Trees, such as red maple, pin oak (*Q. palustris*), juneberry (*Amelanchier canadensis*), wild black cherry (*Prunus serotina*) and aspen, with an undergrowth in part of that of the shrubs and herbs just mentioned, form a well defined forest zone toward the outer limits of the deposit. The unusual relation of alder and heaths, and the fact that the tall shrub zone is in many places higher than the surface of the heath association, may indicate that severe fires (the evidences of which are seen clearly) destroyed much of the peat up to the narrow border near the water where the material was too wet to burn. The portion became the nucleus of the present growth of shrubs at the margin of the lake, and in the depression behind it the heaths have since established themselves.

The peat is more than 17 feet deep, somewhat fluid to the 9-foot level but below this rather compact. Below the 15-foot level an olive-green, layered peat is encountered. The bottom of the deposit was not reached. The chemical analysis of the several peat samples is as follows:

Analysis No. 54

		Air-dried.	Moisture-free.
Moisture		8.98	-------
Volatile matter		51.44	56.52
Fixed carbon		23.52	25.65
Ash		16.06	17.63
Nitrogen		2.02	2.21
Sulphur		0.36	0.40
Calorific value	Calories	4247.00	4669.00
	B. t. u	7645.00	8402.00

The analysis of this sample shows the percentage of ash to be relatively high but the thermal value better than moderate. The sample does not seem typical of much of the material of the bog. The quality of the peat is undoubtedly better above the 10-foot level.

PUTNAM COUNTY

This county holds no peat deposits of economical value. The surface is flat and its general slope is toward the north. Much of the soil is peculiar to the Black Swamp and consists largely of clay intermixed with vegetable matter. Sand and gravel ridges are found in Liberty and Van Buren townships, being in part the shore line of glacial Lake Erie. In the depression between them were formerly several wet, marshy prairies. The Medary Beaver marsh prairie is a deposit of five inches of black peaty soil underlaid by two feet of black clay and an unknown thickness of a typical glacial hardpan. Fossil remains of the mastodon were discovered in the marsh near the center of section 6 and in section 8. All of the peaty area in the county has been cleared, drained and placed under cultivation. The material was not analyzed on account of its high content of mineral matter.

SENECA COUNTY

All of Seneca County west of the Sandusky River belongs properly to, and is a portion of the Black Swamp. All east of the Sandusky

River is high land, and the many depressions in the drift surface are filled with peat varying in thickness from a few inches to five or six feet. The greater portion of the 70 or 80 deposits are small in area, drained and under cultivation. In the northeastern part the deposits rest generally upon sand or gravel and those of the southeastern part are underlaid by a sandy or marly clay. The peat deposits of Seneca County are distributed among the townships, according to the land survey of 1846, as follows: Adams, 3; Big Spring 1; Bloom 1; Clinton 6; Eden 3; Hopewell 5; Pleasant 1; Reed 8; Scipio 2; Seneca 20; Thompson 14; Venice 17. This table does not include deposits less than a few acres in area.

HOPEWELL TOWNSHIP

On the Mohawk road, one and one-half miles south of Tiffin in section 31, on the land of L. Smith are several small deposits of peat. The marsh symbol for this area is not indicated on the Tiffin topographic sheet of the United States Geological Survey. The bog, about 250 feet northeast of the house and the same distance west of the road, has an area of two or three acres. Several borings, so distributed as to test all parts, disclosed an excellent light-brown, compact, fibrous peat three feet in depth, derived principally from sedges. It is underlaid by a sandy blue clay. The deposit is tenanted by spike rush (*Eleocharis obtusa*), bog rush (*Juncus effusus*), several species of sedges (*Carex sp.*), marsh fern (*Aspidium=Dryopteris thelypteris*), several species of knotweed (*Polygonum sp.*), bushes of meadow sweet (*Spiræa latifolia*), wild rose (*Rosa carolina*), and along the southern edge a border of willows.

Directly east across the road is a deposit of perhaps four acres with three feet of peat, covered with water almost the year round. Southwest of the Smith dwelling, is a depression approximately six acres in area, which contains a deposit of peat. Its form is a narrow strip from southeast to northwest. The surface material is fibrous, but sandy and firm. To the depth of five feet the peat is grayish brown in appearance, slightly fibrous and with an admixture of shell marl. At seven feet a sandy gray clay is found, underlaid by a blackish clay containing root fibers. In various places wood fragments are encountered, giving indications of fallen timber. Bog iron ore occurring in irregular patches and frequently in marly accumulations is found along the hillsides. The origin of these deposits is due in great part to the lime left from the evaporation of spring waters which overflowed the surface.

It is said that in Herold's Hollow, about a mile south of Tiffin, on the Mohawk road is a deposit of seven feet of peat, the first foot of which is coarse and fibrous; farther down it is fine and firm, and at the end of the 7 feet plastic. The water which accumulates in the hole washes the peat nearly all out of the augur.

About two miles southeast of Tiffin, near the cemetery, is a deposit averaging about one and one-half feet of peat, resting on a soft gray clay which is underlaid by limestone. It is intensively cultivated and during the past eight years has grown crops chiefly of celery and onions without rotation.

In Honey Creek bottom, in the southeast quarter of section 31, is a deposit forming a narrow strip extending north and south and containing upward of six acres. It is a deposit of fairly good peat; the first two feet are firm and slightly fibrous, but from there down to a depth of 5 feet it is non-fibrous, impure and fluid. A deposit of shell marl underlies the peat but not in quantity for economic use.

There is a similar deposit in section 11, Clinton Township, on the south line of the former Seneca Indian Reservation.

EDEN TOWNSHIP

On the Infirmary farm in the northwest corner of section 5, Eden Township, is a deposit of about 20 acres of peat. It forms a depression on high land and is traversed by a ditch running in a northwesterly direction. It produces clover abundantly and is used for pasture.

A line of testborings was made beginning at a point about 250 feet east of section 6, midway in the field, and 400 feet south of the Clinton Township line, which disclosed the following texture of peat:

At a depth of 8 inches below the surface a black, well decomposed compact material; at 1½ feet a dark-brown, non-fibrous, compact peat; at 3 feet a light-brown, non-fibrous, compact peat; at 5 feet a brownish gray, slightly fibrous, somewhat fluid material; at 7 feet a brownish gray peat with shell marl; at 9 feet an olive-green, fine-grained, fluid peat; at 11 feet a blackish green, fluid, peaty clay; and at 13 feet a pulpy, clayey peat.

Testborings nearer the edge of the field indicate a compact, blackish, non-fibrous peat, 4 feet in thickness; at the 7-foot level a light, olive-green peat, consisting in large part of leaves in layers, is encountered; at a depth of 11 feet the debris is brown, non-fibrous and underlaid by a greenish peat of the same consistency and at the 13-foot level is a black, peaty clay.

In section 6, Eden Township, are a number of small peat accumulations, with a layer of the debris from ten inches to two feet in thickness. Most of the deposits are underlaid by a sandy clay.

On Brook's farm on Honey Creek, an early survey records a bog of "twenty-five or thirty acres; the soil in the immediate vicinity is peaty and the marsh itself is covered with brownish colored water. In penetrating this marsh, a deposit of eight feet of good peat was disclosed and, between 8 and 11 feet in depth, was a deposit composed of lime in calcareous mud intermingled with stringy fibres." The writer did not visit the place.

Extending along Honey Creek into section 7, is the greater part of the Van Meter huckleberry swamp. Fire has reduced the deposit to a thickness averaging less than two feet and it is now under cultivation.

BLOOM TOWNSHIP

A bog is located one mile south of Bloomville; the area and location are shown on the Tiffin topographic sheet of the United States Geological Survey. The bog is traversed by a small stream flowing south into Silver Creek. Along the edges the peat is blackish brown, non-fibrous to the depth of 2 feet, and underlaid with blue clay. At a point 500 feet from the schoolhouse, in a southeast direction, the deposit is slightly deeper. A number of depressions are evidence of former fires.

About one and one-half miles south of Bloomville and 600 feet east of J. E. Miley's house, several testborings were made. They indicate at the 4-foot level a dark-brown, fibrous, matted, very compact peat; at the 5-foot level, a brown, partly fibrous, somewhat fluid peat; at the 7-foot level, a light, grayish brown, non-fibrous, plastic peat, which at the 9 foot level is underlaid by a blue clay.

This portion of the bog was only recently heavily forested and an examination of the stumps showed that swamp oak and soft maple, 19 to 27 inches in diameter, had grown here. The eastern border now supports a similar flora, but the soft maple is more numerous. Other plants are aspen, elm, wild cherry, wild rose and willows.

BIG SPRINGS TOWNSHIP

In the southwestern part of this township is a marsh known as Big Spring Prairie. It is part of an extensive area about ten miles long and from one-half to a mile wide, and has the shape of a horseshoe. About two and one-half miles of its length lie in Seneca County, an area of about the same extent in Wyandot and five miles of it extend into Hancock County. The widest portion of the peat prairie, where it curves to the west, is in Seneca. It represents a depression in the drift and in the underlying limestone which at one time formed a drainage channel, then a lake, later a swampy forest, and only more recently existed as a marsh or prairie. It is interesting to note that the deposit lies almost entirely within the depression marked by the shore lines of glacial Lake Erie. A tongue of this lake, with shore lines almost parallel to each other, extended for some distance eastward. The New Haven marsh in Huron County and several other bogs occur in this old basin.

As a lake the area differed but slightly in outline from the present prairie. Various testborings indicate that the greatest thickness did not exceed 25 feet in Wyandot County, while considerable portions in Seneca County were only a few feet in thickness. That this area was a lake in postglacial times is shown by the presence of old lake beaches or ridges formed by waves and small billowy sand dunes produced by the wind. Similar results are now produced by the action of waves and wind in bays and along the shore of Lake Erie. This peat deposit is analogous in origin and development to the marshes and bogs of Hardin, Huron and Ashland counties, but was sooner drained and brought into an arable condition by the more rapid excavation of its outlet by the Sandusky River and the Timochtee Creek.

Centrally, in section 30, Big Spring Township, occur a number of sand dunes which were blown up by the winds while the prairie site was still a lake. The dunes are located between the Bower ditch on the north and the outlet of Big Spring on the south. Bonser,[1] who studied this region with great detail, finds that as a natural stream the Bower ditch had eroded a perceptible valley on the ridge to the northeast and had doubtless carried a considerable amount of silt into the old lake. The natural currents from the Big Spring and those from the south also carried along some silt. As these two silt-laden currents encountered the sweep of the prevailing westerly winds, much of the material was deposited and in time formed a sand bar or bank. After portions of this sand bar were sufficiently elevated to remain above the water throughout the year, low dunes were formed by the winds. Seeds soon found lodgement and plant life appeared. The same currents which transported the silt also transported many seeds. The general order of the advance of plant life on these dunes resembled that on the dunes along Lake Michigan, as discussed by Cowles.[2] Annuals first appeared, then grasses and sedges which acted as binders for the sand and this made possible low dunes; shrubs and tree seedlings appeared later. A diversified flora gradually established itself, of a character similar to that found today on the miniature dune area in this section. The dunes were formed principally by the southwest, west and northwest winds. The highest portion of this area is about 7 or 8 feet above the surrounding level. The humus overlying the dune sand is from six to eight inches thick. The underlying sand is very fine but of unknown depth.

Three of these dunes are wooded. The most abundant trees are white oak (*Quercus alba*), 18 to 40 inches in diameter,shingle and swamp oak (*Q. imbricaria, Q. palustris*), elm (*Ulmus americana*), 30 to 55 inches in diameter, maples (*Acer saccharinum, A. rubrum*), ash (*Fraxinus americana*), wild cherry (*Prunus serotina*) and cottonwoods (*Populus deltoides, P. tremuloides*). Underneath the trees occur hawthorns (*Crataegus sp.*), red osier (*Cornus stolonifera*), the common blackberry (*Rubus villosus*), wild grape (*Vitis sp.*), climbing bittersweet (*Celastrus scandens*) and smooth sumach (*Rhus glabra*); as a distinct zone along the edge of

[1]Bonser, T. A., Ecological Study of Big Spring Prairie; Ohio Acad. Sci., Vol. III, 1903, pp 1-96.

[2]Cowles, H. C., The Ecological Relations of the Vegetation on the Sand Dunes of Lake Michigan; Botanical Gazette, Vol. XXVII, 1899, pp. 95-361.

the dunes, these and many others form an almost impenetrable jungle. Bonser[1] states that the dune complex is of greater age than either the north or west dune. It is richer in genera and species, and the herbaceous plants are fully four times more numerous than on either the north or west dune.

The depressions between the dunes have a thicker deposit of peat than that overlying the dune sand, but various testborings show that it nowhere exceeds 3 feet in depth. The depressions are tenanted by grasses (*Phleum pratense* and others), several species of goldenrods (*Solidago sp.*) and a few sedges.

The peat of Big Spring Prairie in Seneca County is relatively shallow. At a point 1,000 feet west of the sand dunes and the same distance east of the bridge on the county road, the peat is two feet in depth, black, well decomposed and compact; it rests on a sandy blue clay underlaid by limestone and is under cultivation. North of this point testborings show peat averaging 3 to 4 feet in thickness.

In the extreme southeastern corner of section 31, and 20 feet north of the county road which runs east and west, the deposit is considerably deeper. The surface peat is black and granular; at three feet it is fibrous, and grayish black in color; at 5 feet a grayish sand is found, intermingled with wood fragments. In a few places pockets of a yellow clay occur.

The deepest deposit was met at a point 50 feet north of the county line road on section 32, and 200 feet west of the Hocking Valley Railroad. The field is not under cultivation but is used to a certain extent for pasture. The area is hummocky and in places shows signs of fires. The shrubby cinquefoil (*Potentilla fruticosa*), swamp rose (*Rosa carolina*) and several sedges occur here, but not as frequent as in the area farther south in Wyandot County. The surface peat is well decomposed and dark-brown in color. At 3 feet the debris is slightly fibrous and rather wet; at 5 feet it is brown, slightly fibrous and somewhat fluid; at 7 feet it is reddish brown, slightly fibrous with a distinct odor of sulphuretted hydrogen,—the brass instrument used for sampling the material was stained a bluish purple bronze. At 9 feet occurs a peaty sand with shell marl which is underlaid by limestone.

The analysis of a composite sample of peat is as follows:

Analysis No. 38

		Air-dried.	Moisture-free.
Moisture		11.02	-------
Volatile matter		50.48	56.72
Fixed carbon		20.96	23.56
Ash		17.54	19.72
Nitrogen		3.09	3.48
Sulphur		1.48	1.67
Calorific value	Calories	3831.00	4305.00
	B. t. u	6875.00	7749.00

[1]Bonser, T. A., Ecological Study of Big Spring Prairie; Ohio Acad. Sci., Vol. III 1903, pp. 1-96.

The nitrogen content of this sample is high, but the fuel value is moderate on account of the percentage of silt.

SHELBY COUNTY

The surface of the county is rolling, sloping gently toward the south, and is well drained. Along some of its rivers the soil is largely composed of debris made by vegetation which existed as an extensive marsh on either side of the sluggish water courses. Several beds of peat, which mark the line of the water shed, are found on the upland soils. The shallower deposits seem to have been formed by fallen trees and the work of beavers. Dams made by these animals have been pointed out to the writer at various places. The deeper deposits are in depressions in the drift where erosion is not sufficiently effective to drain the basins.

VAN BUREN TOWNSHIP

The peat deposits in this township are not extensive but rather numerous. In section 10 about 140 acres are reported; in section 14 about 10 acres; in section 22 about 30 acres. Smaller deposits aggregate possibly more than 300 acres. It is said that the majority of them average at least 10 feet in thickness. The deposits which the writer examined occur $1\frac{1}{4}$ miles south of Kettlersville in sections 22 and 23.

Testborings were made on the deposits owned by George Williams. The peat is of a more or less uniform consistency, somewhat fibrous, light-brown, and contains woody fragments. The average thickness in the deeper portions is 12 feet. The sample gives the following chemical analysis:

Analysis No. 86

	Air-dried.	Moisture-free.
Moisture	16.28	....
Volatile matter	47.89	57.20
Fixed carbon	20.48	24.46
Ash	15.35	18.34
Nitrogen	2.23	2.66
Sulphur	0.48	0.57
Calorific value: Calories	3570.00	4264.00
Calorific value: B. t. u	6426.00	7675.00

East of Kettlersville, on the Solomon farm, the peat has a thickness of 19 feet and is similar in texture to that just described. The deposit rests on gravel.

Interest attaches to a note of warning by Hussey of the danger which threatens the destruction of peat beds when they are too well drained for the purpose of bringing them under cultivation.[1]

[1]Hussey, J., Report of the Geology of Shelby County, Geol. Surv. Ohio, Vol. III, 1878, p. 455.

"Where the peat becomes dry it is porous, light and friable. It requires no breaking up to receive the crop, but is only furrowed out to secure precision in the rows of corn, that it may be worked with the plow. The process of drying must continue from year to year where the system of drainage is complete. The result may be disastrous if such a bed of inflammable matter is exposed, as it must be, to the malice or carelessness of any one who might set fire to it in the extremely dry weather of our late summer seasons. Already, imperfectly dried out as the beds are, yet, where persons have carelessly allowed fire to catch in the surface of the peat, deep holes have been burned, extending doubtless to the undried substratum. No means that could be brought to bear in those regions would be effectual in quenching a fire in one of those peat beds if they are once thoroughly dried out. The remedy I would suggest is one of prevention—it is to close up the system of drains during the winter, allowing the water to stand in them, saturating the beds completely. The drains being opened in the spring, the beds of peat would not become fully dried out during summer. By retaining moisture, they will bring better crops and be safe from conflagration."

STARK COUNTY

The surface of this county is generally rolling, and in its eastern portion reaches up to the great watershed between the Ohio and Lake Erie. Like most of the other counties which lie on the watershed, that part is dotted with small lakes and ponds, several of which were long ago filled with peat, while in others the place formerly occupied by the water has been much restricted through the encroaching bog and marsh vegetation. The area and extent of the peat deposits for commercial utilization is not very large.

CANTON TOWNSHIP

West of Canton, about one mile, in sections 6 and 7 of Canton Township, were tamarack bogs which have been drained preparatory to truck farming. The peat is black and well decomposed near the surface, slightly fibrous and lighter in color to the 5-foot level, and coarsely fibrous to a depth of 15 feet. Below this, to the 19-foot level, the accumulation has a greenish color and consists of a laminated peat from sedges and grasses. It rests on an olive-green, plastic mud underlaid by clay and gravel. The chemical analysis of peat from land owned by J. H. Vail is as follows:

Analysis No. 74

	Air-dried.	Moisture-free.
Moisture	10.43	------
Volatile matter	51.34	57.32
Fixed carbon	29.92	33.39
Ash	8.31	9.29
Nitrogen	2.64	2.94
Sulphur	0.34	0.38
Iron	0.17	0.18
Calorific value: Calories	4330.00	4834.00
Calorific value: B. t. u	7794.00	8701.00

The percentage of ash is low while the thermal value and nitrogen content are moderately high.

Near Meyer's Lake, northwest of the city limits, the deposits are shallow. They seem to occupy part of an old valley between Canton and Massillon now filled with gravel and so thoroughly obliterated as to give little indication of its existence, except through a study of the records from borings made for coal. The valley dates from a time when the whole ancient continent stood at a higher level than now. The streams then emptied from highlands to sea levels which have long been obliterated. Subsequent depressions and periods of glaciation filled these valleys. At a later age, when the water of Lake Erie stood several hundred feet higher than now, the line of drainage by way of the Niagara was not open and the surplus water flowed into the Ohio River by several outlets of which this was one. It connected the valleys of the Cuyahoga and Tuscarawas rivers and poured a flood of water and drift across the county, obliterating the preglacial drainage channels and leaving here and there undrained water basins which subsequently became filled with peat. The thickness of the accumulated debris, which is not great, varies between 3 and 5 feet. The peat is dark, reddish brown in color and well decomposed near the surface, somewhat fibrous below and rests on gravel. The vegetation growing on these deposits consists of tamarack trees 18 to 20 feet high, with an undergrowth of shrubs such as poison sumach, high-bush blueberry, several willows (*Salix petiolaris, S. candida*), chokeberry, winterberry, scattered patches of leather leaf, bog rosemary, pitcher plant, sphagnum mosses, orchids and ferns. For comparison the analysis of two samples of peat from this locality is given. The points of interest are brought out in the chapter dealing with the chemistry of peat.

Peat sample No. 75 is taken from a tamarack bog owned by G. B. Samuels. The area has been under cultivation one year.

Analysis No. 75

		Air-dried.	Moisture-free.
Moisture		8.82	-------
Volatile matter		49.01	53.75
Fixed carbon		30.67	33.64
Ash		11.50	12.61
Nitrogen		2.55	2.79
Sulphur		0.34	0.37
Iron		0.18	0.19
Calorific value	Calories	4305.00	4721.00
	B. t. u	7749.00	8498.00

Sample No. 76 represents peat from a virgin deposit covered with tamarack near the portion under cultivation.

Analysis No. 76

	Air-dried.	Moisture-free.
Moisture	8.01	-------
Volatile matter	57.06	62.03
Fixed carbon	29.29	31.84
Ash	5.64	6.13
Nitrogen	3.11	3.39
Sulphur	0.30	0.33
Iron	0.16	0.18
Calorific value { Calories	4518.00	4912.00
Calorific value { B. t. u	8132.00	8842.00

In Marlboro Township, sections 5, 6, 7 and 8, about 600 acres of peat land are under cultivation. Small deposits, aggregating 100 acres, occur in Lake Township, section 14, and in Perry Township, sections 2 and 11. These and the deposits in Sugar Creek, Bethlehem and Lawrence townships near Canal Fulton were not tested.

SUMMIT COUNTY

This county as its name indicates, is situated on the watershed which separates the tributaries of the Ohio River from the waters draining into Lake Erie. The most striking surface feature is the great number of small lakes in basins of glacial drift. They form part of that series of lake basins which mark the line of watershed, and which has been described in the foregoing counties. Many of the ancient glacial lakes have been completely filled by the growth of vegetation, while others show various stages of the process of peat accumulation. Almost every township contains deposits of this kind, some of which are extensive and between 15 and 20 feet in thickness. They are known as cranberry marshes, blueberry marshes, tamarack bogs, cat swamps and peat prairies, according to the character of the vegetation which covers the surface. The larger deposits are in the central part of the county. A few thousand acres, known as "The Plains," formerly presented the aspect of a prairie. It was said to be destitute of timber, and covered with grasses, sedges, a great variety of plants with showy flowers and scrub oak.

West and southward from Akron, beds of gravel and sand form part of a belt which extends through Stark County. They represent an old, preglacial, and now partly obliterated valley of the Tuscarawas which at one time served as a drainage channel from the lake basin to the Ohio. There are many facts which indicate that once a powerful current of water flowed from the lake basin to the Ohio through deeply excavated channels, over falls and through valleys, and that subsequently part of this channel was dammed up by heavy beds of drift, diverting the drainage from the Mississippi system into the lake basin. This channel has been referred to in connection with the peat deposits of Stark County. It is referred to here again, since many of the more extensive peat bogs of the county mark the line of its southern extension.

COPLEY TOWNSHIP

Copley Bog.—The Copley bog extends through three townships in a direction north and south. It embraces about equal portions of Copley, Portage and Norton townships. Its length is about 5 miles and its width from one-fourth to one and one-half miles. The location of the deposit is shown on the Akron topographic sheet of the United States Geological Survey (Fig. 9). The area is traversed in its entire length from the north southward by Shocalog Run, Pigeon Creek and Wolf Creek, and a succession of ponds, designated as Shocalog Lake, White Pond, Black Pond, Yellow Pond and Chemical Pond. In many portions of the bog there are quite large areas of drift hills, kame-like in nature, known as "islands."

At Barberton and north of the city in Norton Township the peat-covered area is narrow, relatively shallow and has lately been contaminated with silt from the embankment of the Akron and Barberton Belt line and from Wolf Creek.

In Copley Township about two miles west of Sherbondy near Akron, the deposit of peat is of great depth. A number of testborings were made on the land owned by M. Stano, in a field partly under cultivation and partly covered with a dense growth of tall weeds (8 to 10 feet high), bog plants and deciduous trees. The peat, which is reddish brown and well decomposed to a depth of 13 feet contains many seeds of water plants and sedges at the 14-foot level. Below this the material is a dark-brown, fine-grained filling, but the bottom of the deposit was not reached with the available length of the sounding instrument. The chemical analysis of the peat sample, from a cultivated portion formerly covered with deciduous trees, such as maple, ash and elm, is as follows:

Analysis No. 59

		Air-dried.	Moisture-free.
Moisture		11.35	-------
Volatile matter		50.39	56.85
Fixed carbon		28.26	31.87
Ash		10.00	11.28
Nitrogen		2.41	2.72
Sulphur		0.81	0.89
Calorific value	Calories	4365.00	4923.00
	B. t. u	7857.00	8861.00

The testborings which were made on the land owned by the Peterson & Wright Company of Akron indicate a depth and texture of peat of the same character as that just described. Through the courtesy of Prof.

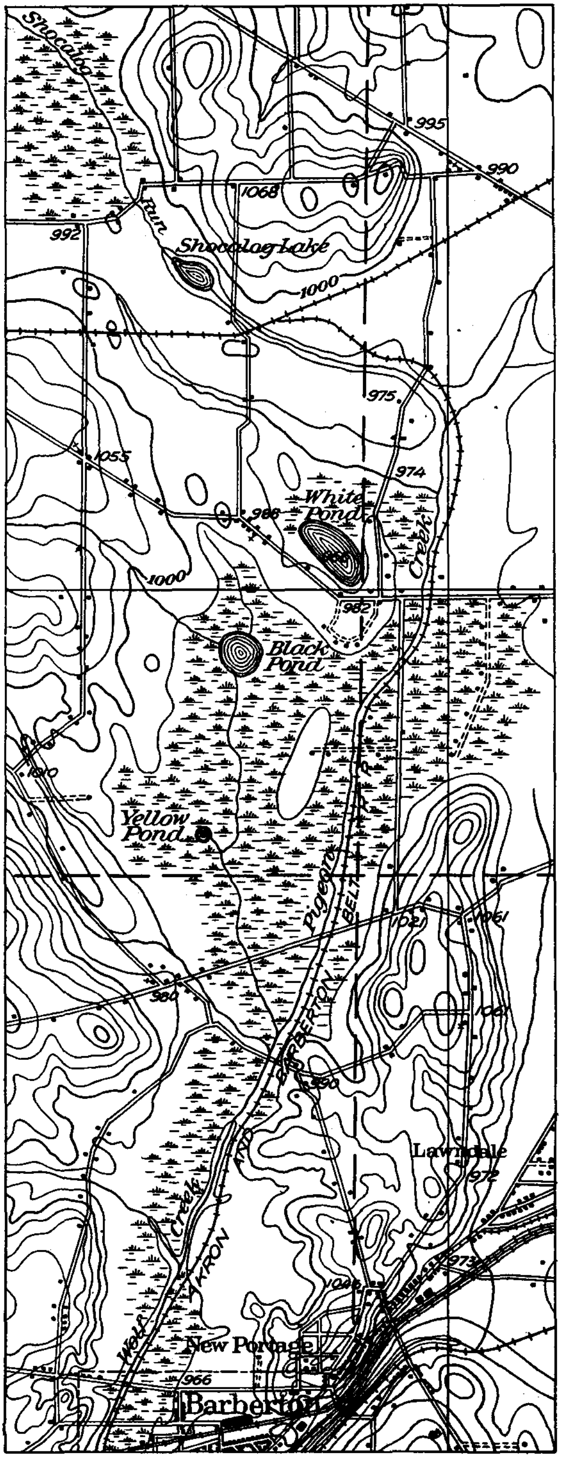


Fig. 9.—Map showing Copley Bog in Summit County.
Scale, 1 inch = 1 mile (2.5 cm. = 1.6 km.).

J. W. Ames of the Chemical Department of the Ohio Agricultural Experiment Station at Wooster, an analysis of five samples is here added. The first three samples represent peat several years under cultivation but of poor crop-producing fertility; the fourth sample is peat one year under cultivation, giving good results; the last sample is a similar grade of peat four years under cultivation.

TABLE 3.

ANALYSES OF PEAT AND ITS ASH.

Constituents.	Peat samples.				
	No. 5302.	No. 5303.	No. 5304.	No. 5305.	No. 5306.
Ash	9.66	14.58	9.84	14.38	11.65
Mn	0.0056	0.0099	0.0220	0.0332	0.0515
SiO_2	3.21	6.18	4.05	5.26	4.01
SO_3	1.20	0.97	1.03	1.03	0.88
Fe_2O_3 and Al_2O_3	2.04	2.91	2.19	2.44	2.65
CaO	2.39	2.87	3.58	3.65	2.80
MgO	0.311	0.331	0.361	0.297	0.345
P_2O_5	0.299	0.345	0.342	0.469	0.337
K_2O	0.1594	0.3117	0.1531	0.2956	0.1860
N	3.42	3.24	3.38	3.10	3.18

The chemical analyses show but small differences in the various grades of peat, and fail to explain the differences in crop production. Biological processes are involved which are of the utmost importance to the life of plants, and which chemical analysis cannot disclose. The more typical features of the correlation must be looked for in a study of the physiological effects of the organic decomposition products of such soils upon plants and in the factors which affect the decomposition of organic matter and limit nitrification in soil. In another chapter the chemistry of peat soils in their relation to agricultural plants is discussed (Chap. XI).

Near the kame-like deposits of drift the peat is naturally more shallow. The debris contains much wood, is often in places more coarsely fibrous and generally rests on a gray quicksand underlaid by several inches of clay, below which in turn is another thick layer of quicksand.

PORTAGE TOWNSHIP

The tamarack grove about two miles west of Akron, along the Copley road and near the intersection of the Akron and Barberton Belt line, is a small remnant of a more extensive bog which formerly covered the area. The tamarack bog is a part of Copley bog (fig. 9), but the swamp symbol is not indicated on the Akron topographic sheet. Signs of fire are in evidence at several places; much of the area is used for pasture. Testborings which were made about 300 feet east of the railroad crossing indicate at the surface a compact, black-brown peat, which becomes fluid at the 3-foot level, and is again compact, slightly fibrous, with fragments of wood to the 9-foot level. At this level the brass sampler was tarnished from contact with sulphur gases. The peat is plastic and slightly fibrous to the 11-foot level, more compact to the 17-foot level and reddish brown and coarsely fibrous below. The bottom was not reached. Farther to the east the testborings indicate a thickness of 15 feet of peat resting on sandy gravel. The chemical analysis of the composite sample from this locality is as follows:

Analysis No. 58

		Air-dried.	Moisture-free.
Moisture		10.54	------
Volatile matter		54.25	60.66
Fixed carbon		25.87	28.92
Ash		9.34	10.42
Nitrogen		2.57	2.88
Sulphur		0.68	0.75
Calorific value	Calories	4327.00	4835.00
	B. t. u	7789.00	8703.00

HUDSON TOWNSHIP

Mud Lake Bog. — This bog and its lake are a part of an extensive peat deposit about two miles southwest of Hudson. It lies midway between the Akron, Bedford and Cleveland Electric Railway, and the Cleveland and Columbus branch of the Pennsylvania Railroad. The bog has a north and south direction, a length of about 5 miles and a width varying from one-fourth to one and one-half miles. The area and locality are shown on the Kent topographic sheet (Fig. 10). Much of the peat deposit is covered with trees and shrubs.

The aquatic vegetation borders the open water in more or less distinct and concentric zones. The submerged association consists of hornwort, bladderwort, species of pondweeds (*Potamogeton sp.*) and others. It is followed by a zone of white and yellow water lilies, among which are several species of floating duckweeds and mats of algae. The pioneers of the land vegetation have their most typical representative in the swamp loose-strife. It forms a concentric zone, and shows only in a few places an admixture of cattail. Toward the outer margin, a narrow belt of meadow-like vegetation shows a variety of herbs such as knotweeds (*Polygonum sagittatum*), arrow head (*Sagittaria sp.*), wood mint (*Blephilia hirsuta*), willow herb (*Epilobium coloratum*), hairy grass (*Agrostis hyemalis*), wood reed grass (*Cinna arundinacea*), common everlasting (*Gnaphalium polycephalum*), swamp fly honeysuckle (*Lonicera oblongifolia*) and bluebell (*Campanula americana*). Adjoining this belt is a zone of shrubs such as buttonbush, willows (*Salix discolor*) and dogwood (*Cornus stolonifera, C. paniculata*) which merge in a succession of taller layers with the broad-leaved trees that surround the lake on all sides. The red maple, elm (*Ulmus fulva*), ash (*Fraxinus quadrangulata, F. nigra*) walnut and an occasional yellow birch (*Betula lutea*) are the species dominating in numbers in the order here given. The undergrowth consists of alders (*Alnus incana*), arrowwood (*Viburnum dentatum, V. sp.*), high-bush blueberry (*Vaccinium corymbosum*), wild cherry (*Prunus virginiana*), spicebush (*Benzoin aestivale*), elderberry (*Sambucus canadensis*), various ferns and heaths (*Vaccinium pennsylvanicum, V. vacillans*).

Several testborings were made in the wooded portion of the bog, about 30 feet from the water's edge. The surface peat is compact,

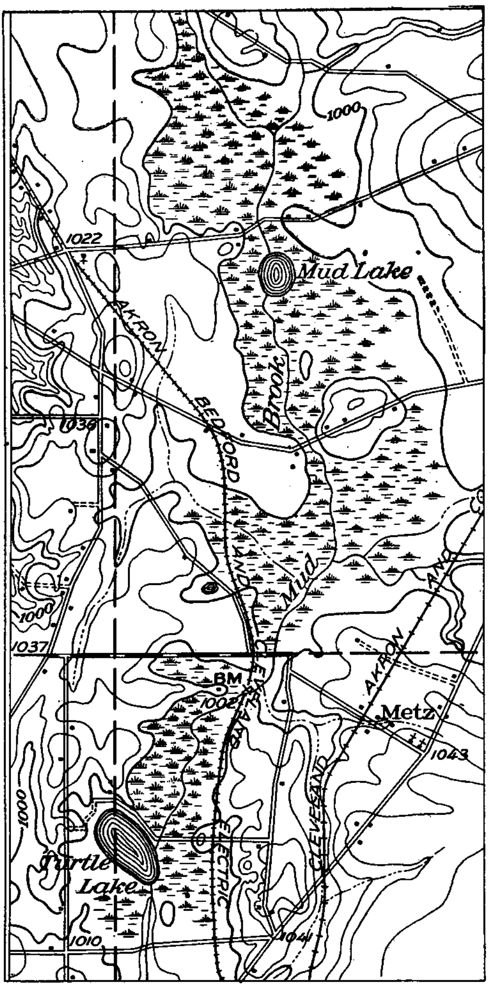


Fig. 10.—Map of Mud Lake Bog and Turtle Lake Bog in Summit County.
Scale, 1 inch = 1 mile (2.5 cm. = 1.6 km.).

dark-brown and well humified; from the 3-foot level down to the 7-foot level the peat is woody and fluid. At the 9-foot level the texture of the debris is more uniformly fibrous, but often woody. Near the 15-foot level the peat is dark olive-green. The bottom of the deposit was not reached at a depth of 17 feet.

The chemical analysis of the composite sample of peat is as follows:

Analysis No. 57

		Air-dried.	Moisture-free.
Moisture		8.91	-------
Volatile matter		54.02	59.32
Fixed carbon		24.06	26.38
Ash		13.01	14.30
Nitrogen		2.12	2.34
Sulphur		0.91	0.98
Calorific value	Calories	4236.00	4651.00
	B. t. u	7625.00	8372.00

North of the road through the bog to Hudson a tamarack grove with yellow birch still maintains itself as a relatively pure stand. The undergrowth is also more northern in character. Repeated fires have enabled nettles, brambles and willows to grow so luxuriantly around the conifer grove as to form an almost impenetrable jungle.

Newberry in his report on the Geology of Summit County[1] reports a long peat bog in Stow Township, the depth of the deposit being not less than 30 feet. In Coventry Township the bogs adjacent to Turkey Foot lakes and along the several water courses bore large quantities of cranberries (Plate IV). There is one deposit in which the peat is said to be 30 or 40 feet thick and from this considerable peat of excellent quality has been manufactured by J. F. Brunot. Deposits of shell marl of great thickness and of bog iron ore also are reported in various parts of the county by the same writer. In the early days of Akron this iron ore was worked in the blast furnaces of that time.

The deposit in the northeastern corner of Twinsbury Township (Fig. 2) has an area approximating 400 to 500 acres. An account of it is given on page 47 (Solon Bog).

In Green Township the peat deposit in section 33 has an area of about 200 acres. The bog was not tested.

TRUMBULL COUNTY

The peat deposits of Trumbull County are interesting in that many of them rest upon deposits of clay which fill wide ancient valleys. The stiff, tenacious drift clays show in many places an admixture of fine sand or angular granitic gravel. The present water courses have been found to run sometimes one hundred feet above their ancient beds, and the peat deposits in the undrained basins are at still higher levels.

The extensive bog in Bloomfield Township, which comprises several thousand acres, is evidently an old lake basin upon a bed of drift clay

[1]Newberry, J. S., Report on the Geology of Summit County, Geol. Surv. Ohio, Vol. I, 1873, p. 207.

Tamarack bog at Turkey Foot Lake in Summit County.

(Photographed by L. King.)

of this nature. The bog extends from Orwell and Colebrook townships in Ashtabula County south almost entirely across Bloomfield Township. One mile east of it is the Ashtabula branch of the Pennsylvania Railway.

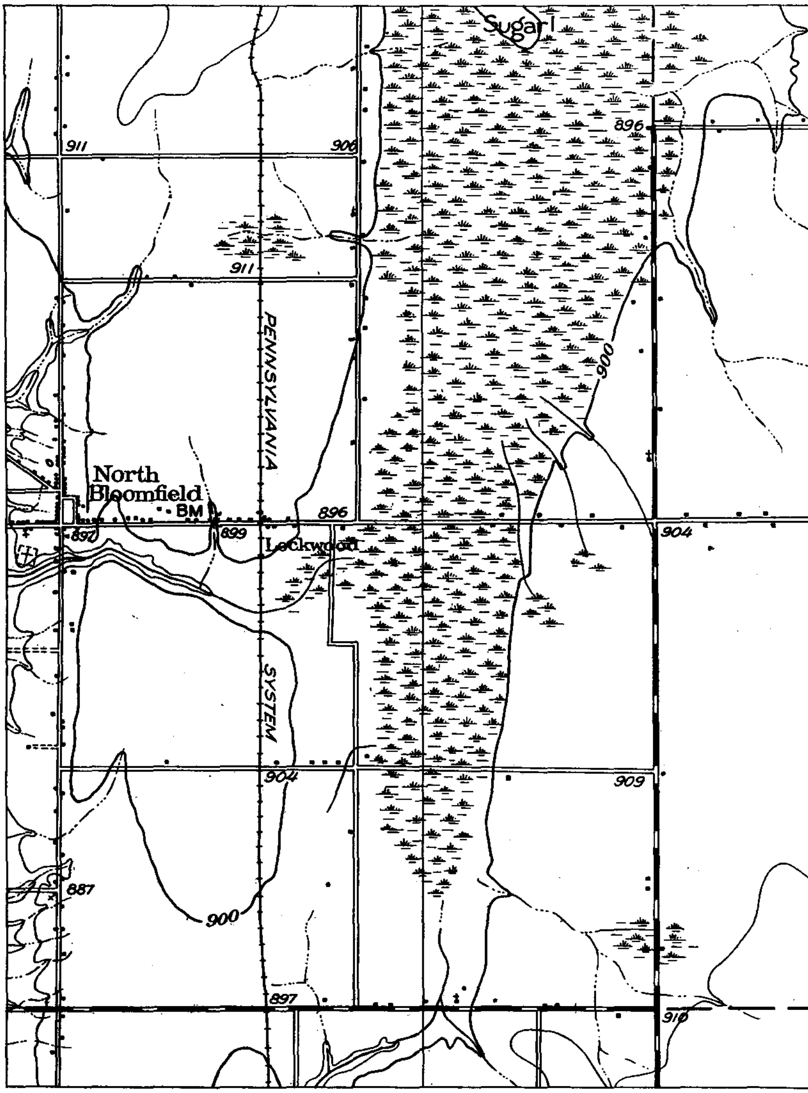


Fig. 11.—Map showing area and location of Bloomfield Bog in Trumbull County. Scale, 1 inch=1 mile (2.5 cm.=1.6 km.).

The area and location of the bog are shown on the Bristolville topographic sheet of the United States Geological Survey (Fig. 11). The basin is now completely filled with peat varying in thickness from one to five feet. Depressions are frequent in which the peat has a greater thickness. The area is severely burned over annually by hunters, and hence most of the bog vegetation, which once consisted of tamaracks, various bog shrubs, blueberry, huckleberry, cranberry and sphagnum mosses, has been replaced in large part by cattail.

Several testborings were made at points along the road leading from Lockport to Greene and along a line north to Sugar Island, passing through the center of the bog. The peat is usually brown and fibrous, except near the surface, and often rather woody. The thickness averages 4 feet. The analysis of a composite sample from this locality is given below.

Analysis No. 45

		Air-dried.	Moisture-free.
Moisture		8.38	-------
Volatile matter		54.63	59.62
Fixed carbon		20.74	22.64
Ash		16.25	17.74
Nitrogen		2.50	2.73
Sulphur		0.34	0.38
Calorific value	Calories	4147.00	4526.00
	B. t. u	7465.00	8147.00

Smaller deposits of peat are found in Champion and Mesopotamia townships. They are heavily wooded, shallow and contain much mineral matter. Of the same character are the scattered areas of peaty soil in Howland, Fowler, Johnston, Vernon and Kinsman townships. The deposits vary between 80 and 100 acres.

VAN WERT COUNTY

The general surface of this county is flat. There is a gentle descent toward the northeast which is however insufficient to drain the land freely. The whole county lies in the Black Swamp region, the features of which have been described in reports on neighboring counties. It was originally densely forested with timber, the species of which are mentioned by Winchell[1] in his report on the geology of the county. There were formerly several large marshes in Harrison, Jennings, Liberty, Tully and Willshire townships—portions of shallow basins between the St. Mary's and the Van Wert morainal ridges. These were continuous when the waters of glacial Lake Erie covered all the northern counties and reached up to the passes in the divide. One of these is now traversed by the Miami Canal at the St. Mary's summit. When the county was first settled the marshes and prairie tracts were characterized by sedges, cattails and similar grasses, and clumps of willow and buttonbush.

[1]Winchell, N. H., Geology of Van Wert County, Geol. Surv. Ohio, Vol. II, 1874, pp. 314-323.

In Tully Township, sections 14, 15, 22 and 23, and also in sections 30, 31, and 32, a large "shaking prairie," also known as the Bear Swamp—is said to have comprised about 18,000 acres. The tract is now under cultivation, but much of the original peat deposit has been burned off entirely. The portions which remain vary in thickness from six inches to two feet. The material of the deeper parts is a dark-brown compact turf that crumbles and burns easily, but contains too much ash to have commercial importance. The deposit rests on yellow clay.

"Twenty-seven Mile Prairie," in Willshire and Liberty townships, is a deposit similar in character and condition to the one just described. The peat samples were not analyzed.

WAYNE COUNTY

Wayne County has no special characteristics distinguishing it from the counties to the west and southwest. It has in part the tableland and the features of the divide which were described for counties to the north. Ancient water channels entered the county from the north expanding into broad alluvial plains and water basins. The several peat bogs and marshes plainly indicate the site of the former waters, several of which are finger lakes. The larger peat deposits are near Orrville and Fox Lake in Baughman Township, and near Creston in Canaan and Wilton townships, extending almost to Canal Fulton in Stark County. The smaller bogs and marshes are confined to Clinton, Franklin, Plain, Sugar Creek and Wooster townships. When the county was first settled there were extensive tracts thickly covered with plants belonging to the bog meadow association and with bog heaths such as leather leaf, bog rosemary, huckleberries and other low shrubs from three to four feet in height. Tamarack, pine, spruce and several tall bog shrubs and many deciduous trees were commonly found in abundance near the borders of the bogs.

BAUGHMAN TOWNSHIP

Orrville Bog. — The location of this finger lake peat deposit is one and one-half miles east of Orrville along the Pennsylvania Railroad. The swamp symbol is not given for this or any other one of the several deposits on the Wooster and Massillon topographic sheets of the United States Geological Survey. Almost all of them are now well-drained and under cultivation. A considerable number of testborings were made on the land of the Brenneman-Eyeman Company. The deeper portions of the deposit consist of fibrous peat, which is grayish brown in color near the 3-foot level, reddish brown to the 7-foot level, somewhat wet and containing fallen timber and similar wood fragments at the 9-foot level, and compact light-brown and non-fibrous toward the 11-foot level. The deposit rests on blue clay. In the shallower portions of the basin the peat is dark-brown in color, only slightly fibrous and otherwise well humified on account of cultivation. For comparison the chemical analyses of three samples from this locality are given below.

Peat sample No. 67 is a mixed sample taken every two feet to the 10-foot level. The area is now under cultivation for onions.

Analysis No. 67

		Air-dried.	Moisture-free.
Moisture		7.00	-------
Volatile matter		57.50	61.83
Fixed carbon		25.28	27.20
Ash		10.22	10.97
Nitrogen		2.78	2.97
Sulphur		0.74	0.81
Calorific value	Calories	4446.00	4782.00
	B. t. u	8003.00	8608.00

Sample No. 68 represents peat from the first foot below the surface layer. It is a coarsely fibrous, reddish brown variety from an area which is now being brought under cultivation.

Analysis No. 68

		Air-dried.	Moisture-free.
Moisture		7.44	-------
Volatile matter		58.56	63.29
Fixed carbon		29.78	32.14
Ash		4.22	4.57
Nitrogen		2.05	2.22
Sulphur		0.27	0.27
Iron		0.20	0.23
Calorific value	Calories	4919.00	5316.00
	B. t. u	8854.00	9569.00

Sample No. 69 is also peat from the first foot below the surface layer, but from an area which has been under cultivation for some time. It is well humified and almost black in color. Originally it had, to a certain extent, the characteristics of sample No. 68.

Analysis No. 69

		Air-dried.	Moisture-free.
Moisture		7.60	-------
Volatile matter		53.35	57.73
Fixed carbon		24.09	26.08
Ash		14.96	16.19
Nitrogen		2.40	2.59
Sulphur		0.38	0.42
Iron		1.28	1.38
Calorific value	Calories	4250.00	4600.00
	B. t. u	7650.00	8280.00

The analyses and the fertilizer value of these samples (table 32) are discussed with greater detail in Chapter XI.

Fox Lake.—This deposit is three miles south of Warwick along the Fox spur of the Cleveland, Akron and Columbus Railway. Its area and location, in sections 1 and 12, are shown on the Massillon topographic sheet. The vegetation is mostly of the typical tamarack and heath bog type, with high-bush blueberry, cranberries in great abundance and a shore vegetation around the open water of the lake consisting primarily of cattails. Severe fires have brought about many changes in the original distribution of the plants. A description of the former vegetation of this locality, as well as of the other bog areas now under cultivation, may be found in the "History of Wayne County," edition of 1878.

A number of testborings were made, which indicate a thickness varying from 3 feet or less along the shallower portions to more than 12 feet of peat in the deeper parts of the deposit. The material is fibrous, brown in color and fairly well decomposed. Peat sample No. 77 is from the deeper portions of the area which supports tamarack trees and an associated undergrowth. An analysis of the fertilizer value of this sample is given in table 32:

Analysis No. 77

		Air-dried.	Moisture-free.
Moisture		7.27	-------
Volatile matter		61.60	66.44
Fixed carbon		27.49	29.63
Ash		3.64	3.93
Nitrogen		2.13	2.30
Sulphur		0.23	0.24
Calorific value	Calories	4712.00	5082.00
	B. t. u	8482.00	9148.00

Sample No. 78 represents various testborings in the tamarack-covered, shallower portions of the bog, very little of which is under cultivation.

Analysis No. 78

		Air-dried.	Moisture-free.
Moisture		8.99	-------
Volatile matter		50.63	54.46
Fixed carbon		23.28	25.02
Ash		10.08	20.52
Nitrogen		2.24	2.41
Sulphur		0.83	0.89
Calorific value	Calories	4069.00	4375.00
	B. t. u	7324.00	7875.00

Both of the samples analyzed show a high nitrogen content, but the percentage of ash in the last is too high for commercial utilization.

West and south of Wooster is a level-floored valley, the bottom of which contains a black carbonaceous soil of a peaty nature. Hubbard[1] recognizes this as one of a group of finger-lake basins in northeastern Ohio.

About one mile northeast of Big Prairie station in the southwestern portion of the county, the floor of another finger lake is easily recognized. Ditches and excavations near the Pennsylvania Railroad indicate in places rather extensive peat deposits on this lake bottom. At several points layers of fine sand and clay occur in the peaty area. The amount and purity of the peat were not determined.

WILLIAMS COUNTY

The topography of the county is generally rolling. Marshes and bogs abound on the surface of the unmodified drift, for the county is divided into two somewhat marked soil provinces by the shore line of glacial Lake Erie. Two ancient lake beaches, only one of which is well marked, cross in a northeast and southwest direction, just east of the St. Joseph River. West of the upper beach the surface consists of unmodified glacial clay with enough sand to render it permeable. Swales and water basins without natural drainage are relatively frequent. East of the upper beach and the second lake ridge near it, the surface presents the features of the Black Swamp,—a plain of rich, friable clay loam, entirely free from gravel and stones and derived from the glacial clay. The general slope is to the southeast, and the descent is gentle and uniform throughout.

It is interesting to note that the majority of the tamarack bogs are west of the St. Joseph River in St. Joseph, Florence, Superior and Madison townships. Crossing the ancient beach to the more level country eastward the bogs with the exception of the strip of peat between the lake ridges, are occupied by elm, red maple and black ash instead of tamarack.

Shell marl is found mingled in all proportions with clay but it occurs only in small quantities. It is said that beds of bog iron-ore have been found interstratified with the marl.

As yet none has been encountered of sufficient magnitude and quality for commercial purposes.

St. Joseph Township. — Much of the peat soil in this township has been destroyed by fire. Testborings were made in section 8 on the land owned by J. McCurdy and F. Cornell, north of the Wabash Railway. The deposit is largely a cranberry-sphagnum peat and is now under cultivation. It is matted, fibrous and light-brown from near the surface to a depth of 4 feet. Below this the peat is quite plastic and rests on blue clay at the 7-foot level. On the farm of Mr. Cornell

[1]Hubbard, G. D., Ancient finger lakes in Ohio. Amer. Jour. Sci., Vol. XXV, 1908, pp. 239-243.

there are pockets of greater depth. Fallen timber is frequently encountered, and at the 9-foot level the accumulation is a peaty marl, light olive-green in color, which rests on blue clay at the 13-foot level. In and near the tamarack groves the material is shallow, the soil in some places consisting almost entirely of peat ashes mixed with clay. The thickness of the accumulation varies greatly, on account of its destruction by fires, so that an estimate of its amount is impracticable. There can be no doubt, however, that it would supply the demand for local uses.

FLORENCE TOWNSHIP

Southwest of Edon the early county survey indicated a tamarack bog three miles long and one-half mile wide. Most of it is under cultivation except an area in section 30 containing approximately 300 acres of an impassable tamarack bog. The trees are in an excellent condition, occurring, however, in scattered groves.

A number of testborings were made in section 30 on the farm of H. Kline in a cleared tract along the border of the bog. The peat is flaky, matted, rather coarsely fibrous and of a light brown color. It appears to be a cranberry-sphagnum variety, and ranges in thickness from 3 to 5 feet, resting on 2 feet of sand with blue clay below. The analysis of sample No. 33 is as follows:

Analysis No. 33

		Air-dried.	Moisture-free.
Moisture		10.12	-------
Volatile matter		57.17	63.61
Fixed carbon		20.98	23.34
Ashes		11.73	13.05
Nitrogen		2.37	2.63
Sulphur		0.26	0.29
Calorific value	Calories	4167.00	4636.00
	B. t. u	7501.00	8345.00

In the tamarack bog northwest of the barn the first 3 feet of peat are compact and well decomposed. From the 5-foot to the 13-foot level the material is very watery, finely fibrous, with fragments and trunks of fallen timber. The bottom was not reached with the length of the sampling instrument.

The vegetation seems to grow on a peat mat of not more than 4 feet in thickness, and over a kettle hole of great depth. Tamarack is the dominant tree, but red maple is almost equally numerous. The undergrowth is the usual one, containing poison sumach, alders, winterberry, chokeberry, mountain holly, high-bush blueberry, black huckleberry (*Gaylussacia resinosa* = *baccata*), saplings of black ash, red elm and oak (*Quercus bicolor* = *platanoides*), various ferns, and sedges (*Carex leptalea, C. stipata, C. lurida*) and hummocks of sphagnum mosses. Willows and aspens, with dogwoods and others, prevail in the burnt areas near the tamarack groves.

The following chemical analysis is that of a mixed sample from the locality.

Analysis No. 34

		Air-dried.	Moisture-free.
Moisture		10.41	-------
Volatile matter		53.70	59.94
Fixed carbon		25.09	28.01
Ash		10.80	12.05
Nitrogen		2.62	2.93
Sulphur		0.30	0.34
Calorific value	Calories	4247.00	4740.00
	B. t. u.	7645.00	8532.00

From four to five hundred acres of peat largely under cultivation are found scattered over sections 28 and 29, but nowhere was a thickness of more than 3 or 4 feet found. The borings show that the vegetable debris is mixed with at least 35 per cent. of clayey material.

Almost in the center of section 29 occurs a bog which seems to have been left undisturbed for some time. It occupies a depression not more than 3 acres in area and is surrounded by low hills. The center of the basin is occupied by cranberries and sphagnum mosses together with the buckbean and pitcher plant. Cotton grass and other sedges and grasses were not noted. Young tamarack trees and saplings of red maple occur near the outer border and are completely surrounded by a forest of red maple, black ash and elm.

SUPERIOR TOWNSHIP

About one mile southeast of Montpelier, along the Wabash Railroad and south of it, is a peat deposit of about 120 acres. Twelve to fifteen years ago it was a cranberry marsh and tamarack bog, but now most of it is under cultivation. A number of testborings were made on the truck farm owned by A. G. Chapman. The peat is generally nonfibrous and dark in color along the border, varies in depth from 6 to 12 feet and rests on blue clay. In the deeper portions near the 7-foot level the material is usually fibrous and very fluid. Near the 11-foot level fragments of wood and roots of trees are encountered, but at the 13-foot level the peat is olive-green, finely grained and compact.

On the truck farm owned by J. S. Underwood more than a dozen borings were made, so distributed as to test the portion of the bog southeast of the residence and along a line parallel with the railroad and at right angles to it. For some distance from the border of the bog the peat is dark-brown, slightly fibrous and scarcely more than 4 feet thick. It rests on a blue clay, but frequently the instrument brought up sand and fragments of black shale. In a few places a layer of angular stony gravel was found above the blue clay. As the deeper portions of the deposit are approached, the surface peat is more coarsely fibrous and mat-like in texture. From the 3-foot level to a depth of 4 feet the material is light-brown, fibrous and rather fluid. Near the 7-foot level fragments of wood are encountered. At this depth the peat has a low temperature, is rather fluid and has a decidedly sulphurous odor. From the 9-foot level to a depth of 13 feet the debris is more compact and less fibrous. At several places the bottom was not reached below the 13-foot level, while in other parts an olive-green, fine-grained peat was encountered at this depth.

The following is the analysis of a mixed sample consisting largely of cranberry-sphagnum peat from this locality.

Analysis No. 90

		Air-dried.	Moisture-free.
Moisture		8.38	-------
Volatile matter		64.16	70.02
Fixed carbon		18.55	20.26
Ash		8.91	9.72
Nitrogen		3.08	3.36
Sulphur		0.22	0.24
Calorific value	Calories	4537.00	4952.00
	B. t. u	8167.00	8914.00

In nitrogen content and in thermal value the deposit is of a high grade and would warrant extensive development.

MADISON TOWNSHIP

Little is left of the bogs and peat deposits which are said to have been extensive in the early pioneer days. Most of them have been burned over, and are now under cultivation or used as pasture. Two and one-half miles northwest of Pioneer, testborings were made in the tamarack bog owned by Mrs. R. Brown. The deposit has an area of about 40 acres most of which is heavily wooded. Tamarack and red maple are the dominant trees with an undergrowth of bog shrub. The greatest thickness of the deposit is 9 feet. The peat is dark-brown and rather fibrous below the 2-foot level. A greenish brown, non-fibrous variety is found near the 7-foot level and passes below into a marly peat. The deposit is underlaid by a bluish, sandy clay.

The following is the chemical analysis of a mixed sample, No. 65, from this locality.

Analysis No. 65

		Air-dried.	Moisture-free.
Moisture		12.01	-------
Volatile matter		56.69	64.43
Fixed carbon		14.58	16.56
Ash		16.72	19.01
Nitrogen		2.14	2.43
Sulphur		0.46	0.53
Calorific value	Calories	4552.00	4947.00
	B. t. u	7834.00	8905.00

The percentage of ash is somewhat high and the thermal value moderate for commercial purposes, but the deposit may possibly prove valuable for local use.

West of Pioneer about 4½ miles are scattered areas of peat, mostly cleared, burned over or in use as pasture. The deposits are rarely more than a few acres in extent. The larger deposit, whose owner could not be determined, has a thickness varying between one and 7 feet. The peat is very compact, chocolate-brown, slightly fibrous near the surface, and well decomposed but rather fluid to the 7-foot level. The samples give the following results:

Analysis No. 63

		Air-dried.	Moisture-free.
Moisture		9.09	-------
Volatile matter		56.56	62.21
Fixed carbon		27.45	30.20
Ash		6.90	7.59
Nitrogen		1.34	2.03
Sulphur		0.19	0.21
Calorific value	Calories	4743.00	5216.00
	B. t. u	8537.00	9389.00

The material is low in ash and of high thermal value and is worthy of careful consideration.

WOOD COUNTY

The surface of this county is broadly undulating, presenting little diversity with the exception of a few sandy knolls and ridges. It holds no extensive peat deposits. The soil is in large part a heavy clay. An area of prairie occupied the more elevated part in the northern and central portions between the Portage and the Maumee rivers. The map, accompanying the report of 1874 on the Geology of Wood County by Winchell,[1] indicates the extent and location. Before artificial drainage was resorted to, these tracts, spreading not infrequently over areas of several thousand acres, were covered in spring with standing water and clothed only with a growth of grasses and sedges. Today the vegetable matter is largely a well humified black muck, and averages a thickness less than one foot.

A number of peat deposits under cultivation were observed south of Bradner in Montgomery Township and along the Hocking Valley Railroad. The area is traversed by low sandy ridges between which the peat lies in basins that were formerly a chain of small lakes and ponds. Underneath the peat is a blue clay intermixed more or less with sand. The peat is light-brown, somewhat fibrous and below the surface layer

[1]Winchell, N. H., Geology of Wood County, Geol. Surv. of Ohio, Vol. II., pp. 368-386.

only sparingly decomposed. In thickness the deposits vary from 2½ to 5 feet. The relatively small areas did not seem to call for a closer inspection with reference to their commercial utility.

It is reported that in Weston, Plain, Liberty and Milton townships, marl has been found.

WYANDOT COUNTY

Wyandot County has several extensive peat deposits which were formerly grassy plains, but never forested. Like many other depressions in Ohio, they are on the higher levels, near the great watershed and give rise to some of the tributaries of Tymochtee Creek. The marshy plains were once the sites of lakes, which later became converted into peat deposits by the slow accumulation of debris from plants growing from the bottom and from the shores of the lakes and gradually filling the basins by their growth and decay.

The more extensive of the deposits is near Carey in Crawford Township. The accumulations near Wharton in Richland Township, those in the southeastern part of Mifflin and the southwestern part of Pitt townships have been mostly burned off to the clay subsoil. The cranberry marshes in Crane and Jackson townships are of less extent, yet in many ways analogous to Big Spring Prairie.

CRAWFORD TOWNSHIP

Big Spring Prairie. — Within the city limits of Carey and north and west of it, extending largely into Seneca and Hancock counties, is the marsh known as Big Spring Prairie. It is an extensive area from 10 to 12 miles long and from one-half mile to one mile wide, having the shape of a horseshoe. The area of the part within Wyandot County is enclosed by two ridges of Niagara limestone, rising to a height of from 40 to 50 feet. The included portion, which is about 2½ miles long and about one mile wide, is drained in opposite directions. Spring Run drains the deposits into the Sandusky River, and "The Outlet" into the Blanchard. The narrowest and deepest portion of the deposit is in this county.

Originally the marsh represented a depression in the limestone, probably as a preglacial drainage channel or an old river valley. A tongue of glacial Lake Erie extended far into the eastern part of the county, and the old beach lines undoubtedly constituted the northern and southern boundary of this depression. The accumulation of drift around it made this a deeper basin which at one time formed a lake, but later became converted into a swampy forest, and only more recently formed a grassy prairie. As a lake it differed but slightly from the present marsh. Testborings indicate that the greatest depth does not exceed 30 feet, while the portions within Carey and the north end of the area near Springville in Seneca County measured only a few feet.

That this area was a lake in postglacial times is shown by the beaches and sand dune soccurring in section 30 of Big Spring Township, in Seneca County. The layer of clay which is found overlying the sand indicates that the valley was occupied for some time by very slow moving water, for only such conditions favor the deposition of the fine mud and a growth of aquatic plants. Soon after the waters subsided a shallow layer of peat accumulated over the clay bed of the lake; later tree seedlings established themselves and a forest began to flourish, where within the memory of man only a typical marsh existed. This is known by numerous tree trunks which were encountered while workmen were digging ditches. A glance at the description of the testborings given below corroborates this view. The diameters of the trunks vary from 6 inches to 3 feet. The tree remains were found in some places near the surface of the peat, while in other portions of the prairie they were found at a depth of 4 and 6 feet. The identity of the several species has not been determined. This forest was destroyed by obstructions of the natural outlets. Beaver dams were probably the most common agent in the sudden rise of water level, for indications still exist showing that not one but a series of such dams were constructed along the area, so that very extensive surfaces came to be covered permanently with water. The trees were killed and fell over and the basin became filled and covered with the accumulation of the annual growth of aquatic plants, sedges, grasses and heaths. Within the peat the horns of elk are said to have been found.

Until recently, it formed for miles a marsh tenanted mostly by sedges and marsh grasses, while the drier portions were natural meadows or distinct heath societies, the latter possessing species quite characteristic of peat bog associations; namely: shrubby cinquefoil (*Potentilla fruticosa*), bog rosemary (*Andromeda polifolia* = *glaucophylla*), swamp birch (*Betula pumila*), and marsh fern (*Aspidium* = *Dryopteris thelypteris*). Less frequently found, are the swamp rose (*Rosa carolina*), poison sumach (*Rhus vernix*) and the buttonbush (*Cephalanthus occidentalis*). In a few places, orchids (*Calopogon pulchellus*) were noted, a silent witness of the character of the former conditions and plant societies. It is interesting to report that in the heath-covered areas, the stinging nettle (*Urtica gracilis*) is very common, and has a rank growth (5 to 7 feet) on the roadsides crossing the prairie, but does not seem to attain a height greater than one foot when growing upon the peaty areas. It is, moreover, the only weed which occurs in moderate quantities among the plants of the heath society.

"Big Spring Prairie" supported various plant associations prior to the degree of cultivation now followed. These varied with the nature and character of relative elevation, proximity to drains and ditches, exposed outcrops, effects of fires and the reversion to marsh conditions. An account of the flora is given by Bonser in the reference cited (page 117).

When thrown open to settlement in 1833, the prairie was covered with water for the greater portion of the year. It is now drained, and, with the exception of a few tracts of "unproductive" heath fields, almost wholly under cultivation. In the drained areas the loosely textured, fibrous peat settled into a firmer, compact deposit. The extent of this movement is shown in the vicinity of Carey by several trees with exposed roots. But especially convincing is a large bowlder, resting on drift clay and located in the northeast corner of the city limits of Carey. A dark band along the side of the rock near the top marks the old marsh level. The portion above the band is old and exceedingly weatherworn, while the portion below has a clean and bright surface. The drop in level of this part of the peat deposit is fully 2½ feet. Borings around the bowlder and at points so distributed as to test various parts of the field, have shown a thickness of peat less than one foot; the well decomposed black muck is underlaid by a peaty clay of a few inches in thickness. This is followed by a fine gray sand resting on the native Niagara limestone.

Northward from Carey the peat becomes deeper and is of better quality. This is shown by the following testborings which were made along a line across the prairie and then at right angles on the Walter's farm about a mile and one-half north of Carey. This portion is in the northwestern part of section 8, Crawford Township, along the 820-foot contour line of the "Upper Sandusky" sheet of the United States Geological Survey. The field is not in cultivation, very hummocky and tenanted by heaths, of which the shrubby cinquefoil (*Potentilla fruticosa*) predominates. The remaining plants are the marsh shield fern (*Aspidium thelypteris*) and dwarfed specimens of the stinging nettle (*Urtica gracilis*). Near the margin of the prairie at the 1-foot level the peat is dark-brown, compact and slightly fibrous; at the 3-foot level the debris is grayish blue, and consists of a sandy clay slightly gravelly below, with fragments of root fibers; at a depth of 3½ feet, limestone was encountered.

At a point 200 feet east of the above testboring and 70 feet south of the road, the peat has a thickness of from 3 to 5 feet; the debris is dark-brown and non-fibrous; at the 7-foot level the instrument brought up a fine-grained peaty sand which is underlaid by a blue-gray sand with fragments of root fibers. At the 8-foot level limestone was encountered.

At a point 600 feet east of the first testboring and 75 feet south of the road, the surface soil is a dark reddish brown, granular peat, changing at the 3-foot level to a fibrous, brown material. Near the 7-foot level the peat is somewhat plastic and fallen timber is frequently encountered. The underlying 4 feet is similar in character; at the 12-foot level the debris is underlaid by gray sand resting on limestone.

The chemical analysis of a mixed sample from this locality is as follows:

Analysis No. 35

		Air-dried.	Moisture-free.
Moisture		10.63	-------
Volatile matter		51.19	57.25
Fixed carbon		25.11	28.14
Ash		13.07	14.61
Nitrogen		2.67	2.98
Sulphur		1.02	1.13
Calorific value	Calories	4157.00	4654.00
	B. t. u	7483.00	8378.00

A number of borings were made at points located centrally in the peat prairie and near the Bower ditch. The character of the peat is similar to that just given, except that the thickness of the deposit averages 14 feet. Mixed sample No. 36 represents the analysis from that portion of the deposit. The samples were collected every two feet in depth to the 11-foot layer, below which the material was rejected.

Analysis No. 36

		Air-dried.	Moisture-free.
Moisture		10.35	-------
Volatile matter		51.14	57.04
Fixed carbon		26.35	29.41
Ash		12.16	13.55
Nitrogen		2.54	2.84
Sulphur		1.28	1.43
Calorific value	Calories	4224.00	4712.00
	B. t. u	7603.00	8482.00

Johnson's Celery Farm. — This farm, a portion of Big Spring Prairie, is located in section 5 about two miles north of Carey. It was brought under cultivation in 1891. Prior to the breaking of the virgin soil the peat was tenanted by various species.

The shrubby cinquefoil (*Potentilla fruticosa*) predominated in some portions, while at other places reed grasses and sedges (*Phragmites communis, Carex sp.*) and herbaceous plants (*Solidago riddellii, S. ohioensis, S. canadensis, Aspidium = Dryopteris thelypteris, Verbena hastata, Lobelia kalmii*) were found. Closer to the ditches were willows (*Salix myrtilloides = pedicellaris, S. candida, S. rostrata, S. lucida*) and other shrubby plants such as birch and poison sumach (*Betula pumila, Rhus vernix*).

Several testborings were made of which the following are typical examples. The samples were taken at points east of the Bower ditch and north of the road extending east and west. The surface peat is a dark-brown, fibrous material; at the 3-foot level the material is brown, compact, coarsely fibrous and rather wet toward the 7-foot level. Near the 9-foot level the peat is fluid and contains quantities of shell marl. Wood fragments and fallen timber were encountered only toward the margin of the deposit which rests at the 14-foot level upon 4 inches of gray sand underlaid by limestone.

It is interesting to note that here as elsewhere, limited areas of peat have been reported as "troublesome" and unproductive for onions or celery. The material contains small amounts of pyrite and at the 9-foot level was distinctly odorous and tarnished the brass sampler. Sample No. 37 is from this section of the prairie.

Analysis No. 37

		Air-dried.	Moisture-free.
Moisture		9.85	-------
Volatile matter		51.54	57.17
Fixed carbon		19.75	21.90
Ash		18.86	20.93
Nitrogen		2.64	2.92
Sulphur		1.76	1.95
Calorific value	Calories	3848.00	4268.00
	B. t. u	6926.00	7682.00

At first, drainage was resorted to chiefly to render the prairie safer for pasturage. Later corn was the crop commonly grown, but it is reported that only three paying yields could be grown in succession on any area. After the third year the yield was small and of inferior quality. Wheat and oats generally proved unsuccessful, "going down" before they ripened. Clover was sown as an experiment, but too many weeds gained a foothold; when mixed, however, with grass-seeds, the soil furnished excellent pasturage.

Since the establishment of the celery and onion culture the land has risen rapidly in value. It is drained by tile every 50 feet, but ordinarily by means of lateral ditches 4 to 5 rods apart. On account of the cold soil water from springs and ridges, it has been found necessary in addition to resort to open ditches. At present the principal agricultural products are onions, celery, potatoes and various kinds of garden truck. The crops are occasionally injured by late frosts and also by the sandblast action of the dry surface soil readily blown about by the winds. Where this occurs frequently, rows of trees should be set around the fields as wind breaks.

CRANE TOWNSHIP

An interesting, though small deposit, is a former cranberry marsh on the land of H. A. Langley one and one-half mile north of Upper Sandusky on section 19 of Crane Township. It is a semicircular area of possibly 200 acres, the form and location of which are shown on the Upper Sandusky sheet of the United States Geological Survey. The peat deposit occupies a basin in the drift clay, and with the exception of a few "holes" is relatively shallow. Over 20 borings were made along two lines at right angles, and at points so distributed as to test nearly all parts of the field. The entire section is well drained and under cultivation; the present (1910) crop, sugar beets, is an experiment.

The surface peat is generally light-brown, and consists in large part of broken pieces of the matted, fibrous variety. Beneath this is found a layer of blackish brown, well decomposed peat, averaging about one foot in depth, resting on a marly clay. For a distance of 200 to 350 feet from either margin no thickness of peat greater than two feet is encountered. The southern margin shows indications of fires.

The testborings toward the central portion of the deposit indicate a blackish brown, well decomposed and compact peat near the surface, which passes below into a light-brown fibrous and frequently woody variety. At the 5-foot level the peat is usually olive-green in color, fine-grained and intermingled with rhizomes and the laminated remains of marsh grasses. The deposit rests at the 8-foot level on a plastic blue clay.

In the deeper depressions of the basin the peat is similar in character. A light-brown, woody, but otherwise fluid, variety with fragments of shrubs is encountered at the 5-foot level. At the 7-foot level the peat is fibrous and contains many rhizomes of sedges and grasses. It rests at the 9-foot level on a grayish marly clay.

A composite sample from these testborings has been analyzed and the results follow:

Analysis No. 39

		Air-dried.	Moisture-free.
Moisture		8.84	-------
Volatile matter		47.26	51.85
Fixed carbon		22.90	25.12
Ash		21.00	23.03
Nitrogen		1.96	2.16
Sulphur		1.98	2.18
Calorific value	Calories	3881.10	4259.00
	B. t. u	6986.00	7666.00

A study of a number of testborings makes it seem evident to the writer that the cranberries and sphagnum mosses appeared after the sedges and marshy grasses had built up the surface of the bog; and that the margin of the deeper depressions was early occupied by bog shrubs, willows and others. Obstructions in the natural drainage, probably due to beavers, caused a sudden rise of the water level and consequently the destruction of the bog shrubs. In this deposit the plants followed later the same succession as those which were fully examined in a cranberry marsh near Columbus and in various places in the northern peninsula of Michigan.

CHAPTER IV

THE USES OF PEAT*

CHARLES A. DAVIS

Introduction.—Other chapters of this report have fully described the occurrence and origin of peat in Ohio and the qualities which give it value as a fuel, and which must be considered in converting it into a salable product on a commercial scale. Before successful production can be made even in a small way, however, other points must be taken into account depending wholly on the properties of peat and its fitness for specific uses. Consideration is given some of these here as an introduction to the more technical part of the paper, because the success or failure of any or all attempts to make any product from peat is based on fully understanding them. They have been often overlooked or deliberately ignored by those about to enter upon or promote the manufacture of peat products in the past, but the need of such a discussion is clearly shown by a glance at the history of the numerous attempts at making peat fuel that have been made in the United States during the last fifty years. Large sums of money, aggregating many hundreds of thousands of dollars have been spent upon such enterprises, from which no financial returns have been received by their supporters.

These facts are so well known in some sections of the country where there are numerous peat deposits that a large part of the conservative investing public can no longer be interested in any enterprise based on peat utilization, no matter how attractively it may be presented. This section of the report is designed to show that causes which are avoidable have been chiefly responsible for the losses and failures of peat enterprises of the past—not a lack of desirable qualities existing primarily in the peat itself and in the products made from it.

PRINCIPLES GOVERNING PROFITABLE UTILIZATION OF PEAT DEPOSITS

To state the matter simply, the study of unsuccessful peat-fuel plants in this country, and an analysis of their history, emphasizes the fact that a number of important matters must be taken into account before any peat bog can be made the source of a paying business, even when the peat is of good quality, and can be shown to be valuable fuel if rightly treated. It seems clearly obvious from such examination that much of the lack of success observed has been due to failure to take such factors into account, to ignorance of their existence, or to too great optimism when they were under consideration.

The most important single group of such errors may be charged,

*Largely adapted from Bulletin 16, Bureau of Mines, by Charles A. Davis.

perhaps, to ignorance and inexperience. Ignorance is not excusable, however, since there is a very considerable mass of literature in nearly every European language, which details at length records of the theoretical and business experience gained during more than a hundred years of experiments. Although these experimental data have been gathered under economic conditions differing somewhat from those in America, the difference is not so great that the results can not be made applicable here; to entirely overlook or throw them aside is to invite failure when success might almost as easily be attained. For example, much greater progress could be made in a given time by taking the best types of European machinery and processes for manufacturing peat and improving them than by beginning anew and working out similar ones independently. Large sums of money and much disappointment would also be saved.

Many of the difficulties which have been encountered in peat utilization in the United States, as well as some of the failures, may be attributed to what may be termed "faulty engineering." Under this head may be grouped mistakes made in choosing sites for the erection of plants; poor planning and erection; unwise selection of the kind of product to be made and the way to make it; the choice of inefficient machinery by which it is to be made; and even in imperfect prospecting, surveying, and proving up peat bogs.

There have also come to the attention of the writer many cases in which certain fundamental business considerations seemingly have been ignored or overlooked, thus predestining the ultimate collapse of the enterprises.

As the results of overlooking or neglecting these factors have been observed in many parts of the country, persons who, without previous experience, are considering investment in some form of peat utilization, may be helped by a brief statement of some of the economic and related principles that must govern the founding and successful growth of any business that has the use of peat as a basis. Attention may in this way be directed to some of the dangers of loss which may be encountered as the result of inexperience.

Market. — One of the first objections raised against the use of peat for fuel is the one made by economists and others that the State is already so well supplied with good fuel in other forms, such as wood, coal, oil, and gas, that there will be no sale for peat; they contend, *a priori*, that there will be no market for peat fuel; hence investigation of its possibilities is useless. The market is rightly considered to be the most important factor and the one upon which the fate of any peat development must hinge, for unless the product of an industry finds a ready sale at prices which will meet all costs, maintain the plant, and give a profit on the capital invested, it can have no permanence— in fact, there can be no industry.

At first thought, any desirable type of fuel, would seemingly find a ready sale at good prices, but more careful consideration will raise the question as to whether a substance like peat, which is quite unknown and untried in most American fuel markets, will be accepted by any number of buyers until they have learned by experience that it may be depended upon. Experience shows that most people are conservative in adopting new materials in place of those which they have long known and have found satisfactory. The conclusion may be drawn, therefore, that the market for any form of peat, as for other new materials, must generally be won by slow and persistent effort, in which a first-rate product, skillful manufacture, careful advertising, and constant demonstration must be combined.

The important markets for fuel are located in the larger towns and cities; hence a peat-fuel factory should be situated where one or more large centers of population and manufacture can be worked up for a market. It must be remembered, however, that the fuel trade in such places is thoroughly and closely organized, and therefore opposition must be expected to any new and independent product. This opposition, if effective, will result in reduced sales, in lower prices, and obviously in smaller profits during the stage while competition from these agencies is active.

A good market, then, generally must be built up. Not less than five years after peat fuel is put on a given market would probably be needed for it to find its proper place among other fuels. At the end of the period peat could hardly be expected to form more than 10 per cent. of the entire quantity of fuel used for all purposes in the region surrounding the proposed plant.

Conversely, time is needed in all new manufacturing enterprises to get the plant to a stage where its efficiency permits other than slow and expensive production. This period of development ought to be the time when a market is being secured and established so that the product as fast as it can be made will be taken at fair prices, and so that as soon as a full and satisfactory output is attained the whole of it can be sold with profit.

So far as can be seen at present, or can be judged from European experience, it will not be feasible to send peat fuel long distances by rail. Indeed, the closer to a good market that it can be produced, the more certain will be the chances of success. The abundance and prices of other kinds of fuel, the means of transportation, the attitude of the transportation companies, the conservatism of the population, and the way in which the peat is prepared will all be factors in determining the maximum distance that can be reached by a given peat-fuel factory. This maximum distance will presumably be less than 50 miles for a long time after the factory has reached a productive stage.

The market within this radius can be secured only by making a uniform product with enough good qualities to displace fuels which have been known long before the time of its introduction. The peat must be fairly and honestly shown to be really desirable, and the more honestly the demonstration is made the more profitable will be the final outcome.

Transportation Facilities.—It will probably not be possible for a long time in the future to utilize as a source of fuel peat bogs that are unfavorably located in respect to lines of railroad already built, or to water routes, such as rivers, lakes, and canals. The possible exception lies in bogs which may be utilized by producer-gas plants where the peat is converted into electric energy at the bog, or into fuel gas that may be conveyed by pipe lines to the places where it is to be used. Both of these uses are quite practicable, but are likely to be slowly developed, because of the conservatism of capital in taking up entirely new lines of investment.

It is important, therefore, to be assured that good transportation lines to the site chosen for a peat-fuel plant are already in existence, or will be before the plant is built. The cost of every item is so much increased where teaming is necessary, that, except on a very small scale, a plant can not be established and brought to a successful production with this sort of transportation. The limit to which the finished peat fuel can be drawn by horses and sold at a profit is easily determined when the cost of production is added to other charges, including the cost of men and teams, and subtracted from the selling price.

Location.—Closely connected with the factors which have been mentioned is that a choice of location of a bog on which to establish peat operations. Too much importance can scarcely be attached to this, as the success of the enterprise depends not so much upon the quantity of peat to be manufactured as upon the cost of production and marketing as compared with the price at which sales can be made. Clearly, therefore, a small, favorably located bog is preferable for commercial exploitation to a large one remote from market, transportation lines, and cheap labor supply.

The margin of profit on the finished product of any type of peat-fuel plant will be so small, because of the low price at whch it must be sold in competition with coal and wood, that no extra charges should be placed on its production by a choice of location that will entail a high cost for labor and maintenance, and slow, uncertain, and expensive transportation to market. The greed that urges the promotors of projected enterprises to get the largest possible quantity of raw material may blind them to the handicaps caused by its location, and thus bring the entire investment to a disastrous end.

Amount and Quality of Peat To Be Utilized.—An estimate of the life of the plant, its size, and consequently the amount of money invested, must be determined by the total quantity of good peat in the bog selected for use; hence an approximately accurate knowledge of how much peat can be had is essential before other plans are made, especially if the deposit is of small area and depth. If it is very large, the need of care in this respect is not so great as when the quantity is clearly limited; in all cases, however, sufficiently exact tests should be made to insure the fact that the contemplated investment is justified by the quantity and quality (p. 18) of good raw material available.

The quantity of peat in a given deposit may be determined with sufficient accuracy for practical purposes by finding its total area and average depth, and assuming that at least 200 tons of air-dry machine peat can be made per acre for each foot in depth. Some heavy types of peat will yield more than this, and the figure is seemingly conservative for American peats, which in practice generally give a dense, heavy product.

So many erroneous ideas have been expressed as to the lower limit of size of bogs that may be used for making peat fuel that the following illustration is cited to show that in Europe bogs of small size are used even where considerable investments are made. At Skabersjo, Sweden, a producer-gas plant equipped for generating electricity, and costing several thousands of dollars, has been erected at a peat deposit 37 acres in area and averaging 5 feet deep. The life of the plant is estimated at 30 years at the present rate of consumption of fuel, of which there is estimated to be 44,500 tons available. There are other bogs in the neighborhood which may be used after the one now in use is exhausted, but none is of great size. The plant develops 300 horsepower.

The illustration mentioned indicates that small deposits of peat of small average depth will justify exploitation if the plans formed are not too ambitious, as the annual production of 1,000 or 1,500 tons of peat fuel can be assured for a long period of years from such bogs as the one cited. Such a quantity may be sufficient to furnish all that will be taken by a good-sized community for several years after a plant is built. It should also be taken into account that a number of years would probably elapse before so large an output could be made by the plant or be taken by local markets.

There are many small towns in northern Ohio near which are sufficiently large beds of peat to supply electric current for many years for lighting and other uses. Likewise, power for factories and mines—where now the fuel used is coal shipped by rail—might be cheaply obtained from near-by peat beds.

The physical properties of the peat beds under consideration should be such that the raw material may be easily dug and easily and rapidly put into the desired form of product with the chosen machinery. If condensed or machine peat to be shipped from bog to market by rail is the product decided upon, the peat should not be very fibrous or woody. These qualities, however, do not reduce its value so much for local use, except as stumps and other remains of trees increase the cost of digging, which in most cases will be small per ton of final product.

Methods of Prospecting Peat Bogs and Estimating Their Contents. —Peat beds of large area and considerable average depth are rather rare in the United States, and where they do occur are often so located with respect to lines of transportation or to markets that they could not be used at present except for the production of gas for power generation. Bogs of this class need little careful prospecting, as the quantity of peat in them is very large, and ordinary errors in the relation of the estimated quantity to that actually present may be disregarded when a quantity of material sufficient to warrant exploitation is known to be present.

There is greater need of carefully testing bogs of small area, and the cost of doing this is relatively small. After the area has been found by an ordinary land survey, a series of parallel, uniformly spaced lines should be laid out at right angles to the long axis of the bog and entirely across its surface. Along the lines test holes to the bottom of the deposit should be made to determine its variations in depth. The intervals between the holes should be of the same length, and in final proving up should be dug as deep as possible with a spade or post-hole digger. An earth auger may be used for sounding the depth and for taking from below the surface samples for chemical analysis.

The chief objection to the use of the auger lies in the fact that in deep deposits the sample taken at a considerable depth may be stripped from the auger as it is drawn up and may be replaced by the material through which it is drawn, so that the origin of the sample may be doubtful.

A much more exact tool is one devised by the author and used by him with great satisfaction for several seasons. The essential part of this tool has been described on p. 29. By using this tool carefully and thoroughly the depth and character of any peat bed may be accurately learned with a relatively small expenditure of time and labor. Only by digging with a shovel, however, can be had the large-sized samples that ought to be used in final tests. The large samples are more satisfactory for examination and may give more characteristic results than those taken with the testing tool described.

Small and medium sized bogs which fill deep depressions below the ground-water level, like lake basins, may be expected to have open water or a layer of very watery peat below the thick, firm turf that forms the upper 3 or 4 feet of the bog upon which large trees may grow. Where such watery deposits occur they must be examined with unusual care, because of the amount of water may occupy so much of the basin that the peat could not be worked profitably. In one such basin in Michigan, where the turf supported a growth of trees and was so strong that a railroad was built upon it entirely across the basin, more than 60,000 cubic yards of earth were used to give the track stability after the traffic had become so heavy that the turf would no longer support the weight of the grade, tracks, and train. Manifestly, this bulk of earth would fill only a small part of the space occupied by water and watery peat in that basin which hasty or inefficient testing would have determined to be filled with compact peat.

The possible occurrence of marl should also be watched for in basins the upper levels of which have good peat beds. This precaution should be taken especially in those parts of Ohio, where the ground water, as shown by its hardness, contains much lime and where marl deposits are of frequent occurrence. Such deposits are often covered with peat to the depth of several feet and may also be interbedded with it. If an auger or ordinary sounding rod is used in testing such deposits the marl may not be found because, as indicated above, the peat of the top strata may replace it in the auger and lead to the conclusion that the entire deposit is of peat and that a much larger quantity is available than really exists. Beds of soft, fine clay underlying peat in basins may be equally deceptive.

If a close approximation of the actual quantity of air-dried machine peat which a bog contains is desired, a considerable number of measured cubic yards should be dug from different parts of the deposit and from different depths and each of these macerated separately. After thorough drying by exposure to the air for some weeks the resulting blocks should be weighed; the average of the series will give the number of pounds of marketable material per cubic yard, and this multiplied into the number of cubic yards in the entire deposit and reduced to tons will give approximately the total weight of the entire available mass of peat. The more thoroughly the sample cubic yards are distributed over the entire area and depth of the bog, the more valuable the data obtained will be. In making estimates and the tests upon which they are based, the turf and the poorly decomposed top stratum of peat for a foot, more or less, below the surface is not usually included.

It is perhaps worth while to point out here the urgent necessity of having all surveying and testing work done thoroughly and by competent men, as money expended on these determinations gives information without which it is impossible to proceed with any certainty to the making of investments; lack of knowledge or a wrong estimate may lead to overconfidence and serious financial loss, or to entire failure.

Chemical Tests. — The use and kinds of chemical tests are discussed in Chapter XI, but for persons who may wish to know how to make preliminary examinations of peat for themselves the following directions are given. The recommendation is made that any preliminary tests be confirmed before the peat is utilized for commercial purposes. Analyses by a competent chemist who has the proper apparatus and laboratory equipment to do the work accurately and inexpensively are the most satisfactory.

The equipment needed for such preliminary tests as need to be made are: (1) Some form of weighing apparatus that will give a reasonable degree of accuracy. If the scale is not sensitive, a large sample of peat must be tested. (2) Some form of metal or earthen vessel in which the peat can be weighed and burned. For this purpose a small pressed metal cup will answer. Before using, it should be thoroughly heated to burn or melt off any substances that would later be lost in this way. (3) A stove or burner in which a clear, smokeless fire can be kept up; a gas stove is ideal for the purpose. (4) Metal tongs or forceps for use in handling the cup when it is hot.

The testing of peat as fuel begins with the air-dried material, although if the quantity of water the peat contains in the bog is desired, this can be ascertained by taking a sample just as it is dug and keeping it in a tightly closed glass fruit jar until the desired tests can be made.

To find the percentage of water in the peat, a sample is removed from the storage jar to the clean, dry cup, which should be weighed as accurately as possible beforehand and the weight recorded. The combined weight of the sample and cup is next ascertained and the weight of the peat obtained by difference. The cup containing the sample may then be placed on a hot steam radiator or in the top of a vessel of boiling water and dried until there is no longer loss of weight after repeated weighings. The difference between the original weight and the last is the amount of water evaporated. By the same method, the percentage of water in an air-dried sample can be found, the drying being hastened by thoroughly pulverizing the peat before it is weighed. In drying samples in these operations care must be taken not to heat the peat much above the boiling point of water on account of the ease with which some of the volatile matter is driven off, causing too great a loss of weight.

After the water is all driven off (a state indicated by no loss of weight when the sample is reheated) and after the weight of the sample is correctly noted, the residue should be set on fire and carefully burned, stirring with a clean wire being resorted to to make combustion complete. When the ash is nearly white, and no unconsumed particle can be seen, the dish should be allowed to stand till cold and the ash and dish weighed. The weight of the dish subtracted from the weight of the ash and the dish is the weight of the ash.

If it is desired to know the quantity of coke that a given peat sample will yield, the sample should be weighed in a cup with a loosely fitting cover, and the cup and sample placed in a flame or a clear fire and heated to redness until gas ceases to come off. The gas will take fire around the cover, and as long as it burns the heating should be continued. As soon as the gas is all driven off, the cup, tightly covered, should be cooled and weighed again. The difference in weight is the weight of the volatile matter, including the water in the peat, and the residue is the coke, which is the fixed carbon plus the ash.

The density of a given peat may be determined by cutting out a block of such shape that it can be exactly measured and comparing its weight with that of the same number of cubic inches of water. If the block is made to contain an exact number of cubic inches, the operation will be easier. A cubic inch of water at 60° F., the ordinary temperature of the air at which weighings are made, weighs 252½ grains.

In most of the large cities cheap laboratory appliances can be bought, and these will serve for making the required tests. In the same cities, too, will be found commercial testing laboratories where satisfactory fuel-testing work is done at reasonable rates. There are several educational institutions in Ohio giving courses in mechanical engineering or technical chemistry which also have good equipment for making fuel analyses. The essential elements to be obtained for comparison are the ash content and the theoretical fuel value expressed in calories or in British thermal units (B. t. u.).

Mechanical Tests. — According to observation and experience an examination into the mechanical structure and qualities of peat is of more value than a chemical analysis. This is especially true when the material has been selected for a single specialized use requiring a large outlay of money for a properly equipped plant. The importance of carefully investigating the deficiencies of peat, as well as its good qualities for the intended use, is emphasized and should not be overlooked. The defects, the cost and difficulty of handling, the large percentage of water and waste matter as compared with that of usable material, and other qualities of similar nature must be investigated. The more specific the proposed use the more thorough and complete should be the preliminary investigations. As a part of such tests the selected machinery should be tried under conditions as nearly as possible like those of the factory, with large samples of the chosen peat. The samples should be of not less than a ton in weight and of larger size when they can be had, and the tests should be made before any plans for installation of a permanent nature are developed.

Samples used in such tests should be carefully collected, so that they include material from well separated parts of the bog and from as deep below the surface as the peat can be reached with the usual tools for digging. The costs of these tests may seem excessive, but in the end are justified by the results obtained, whether satisfactory or not. If the peat thus tested turns out to be unsuited for the purposes for which it was chosen, the expense is especially justified.

When such tests are made it is probably more satisfactory to send the material to the factory of the makers of the machinery, where installation is complete and skilled labor is available, rather than to try to set up the machinery temporarily at the bog; by the former course more valuable results will be obtained at much less cost. The tests should be made under the inspection of some competent and disinterested observer who is retained to guard the rights of both parties concerned.

The great importance of thus trying machinery and peat together before erection of the plant has been fully demonstrated in this country. In at least two instances more than $100,000 have been spent in the development of elaborate peat-fuel plants which were never successfully operated. The reason for their failure was that the machinery which had been installed could not manufacture the peat available into the desired product or any other that could be sold at a profit in accessible markets. Other examples less impressive might easily be cited in which lack of success seems clearly referable to the omission of thorough preliminary testing.

Sources and Percentage of Ash.—Peat containing a large quantity of ash is not as good fuel as that containing a less percentage, because the former type gives less heat for a given unit of weight. The ash of peat deposits, as noted on p. 379, is derived from the mineral matter gathered by the growing plants that have built up the peat. Mineral matter may also be brought in by the water by which the plant remains have been protected and preserved from decay, or may be blown in by the winds. The mineral matter derived from the water is carried either in solution or in suspension and may reach the peat continually with the water or be supplied intermittently by overflow from lakes, streams, rain rills, or springs.

When peat deposits are being tested those in which the peat is grayish or greenish, or contains whitish or red streaks and spots when dry, or shows shining specks of mica, or is gritty when ground between the teeth, may be classed as of poor quality for fuel unless their analyses prove otherwise. In such deposits the ash content is generally found to be high.

Peat beds that lie in the flood plains of brooks and rivers, in deltas of streams, or on terraces or slopes watered by springs whose waters are perceptibly mineralized, seldom pay for testing unless in a region where all kinds of fuel are scarce. All of these types of peat beds are certain to be somewhat deteriorated by mineral matter; hence the peat has its fuel value and its possible market value lowered by the presence of too much ash.

In certain parts of Ohio peat beds in basins, even when no important streams enter them, are sometimes found to be rich in ash. This condition is caused by the presence of plants that concentrate in their cells or tissues or on their leaves and stems some of the minerals brought in by springs or other sources of water supply. The minerals are left on the bottom with other debris at the end of the cycle of growth of the plants. Calcium, magnesium, silicon, and iron compounds are thus segregated from lake waters and become part of the ash of peat.

The effects of the action of waves and currents on sandy or muddy lake shores also must be considered as a source of mineral matter in peat beds exposed to the wash of these sediment-transporting agents. Consequently peat on the banks of lakes having wide stretches of exposed sandy and muddy shores must be tested very thoroughly before using it for commercial purposes.

On the wind-swept sandy areas, such as dunes, much fine mineral matter in the form of dust is blown into low places, where it is left and becomes a part of any peat deposit which may exist there.

Preparation of the Bog For Use. — In making the preliminary examination of a bog the quantity and kind of vegetation on the surface of the deposit should be carefully noted. If trees and shrubs are present, their kind, size, and relative abundance should be observed. The presence and frequency of roots, stumps, and buried logs should also be determined at the same time. Where trees are present and their buried remains are abundant the cost of getting the ground ready for digging the peat will be very materially greater than in a grass-covered bog. On the other hand, the wood may be sold or used for fuel at the plant, and the work of clearing may be done at times when weather or other conditions are unfavorable for production, thus keeping the force of laborers at work. It is also apparent that only a small area will be used at a time, and that the preliminary work will, therefore, be distributed over a long period, so that it cost per ton of peat produced will usually be so small as to be insignificant.

When all things are taken into account, however, and a choice of bogs can be made, that which has many buried logs and stumps should be avoided. If the woody material is confined closely to the surface layers, little account should be taken of it, because it is easily removed. The deposit below such layers is often more decomposed and compact than where trees have not yet become established.

Drainage of Peat Deposits. — In European countries, where peat is dug extensively by hand, the general practice is to plan and carry out an elaborate system of drainage, so that the water content of the peat is perceptibly lowered before digging is begun. Aside from the greater convenience in digging insured by drainage, the water content is lowered to a considerable extent, although not so much nor so rapidly as would be expected, because of the water-holding powers of the peat.

Drainage becomes of importance, however, whenever the greatest economy of handling the wet peat is sought, as it should always be if dug by hand. Reference to the table giving relation of the percentage of water in peat to its weight (p. 170) will show that, if the water content of a given weight of peat is reduced from 90 per cent. to 80 per cent. its weight will be decreased 50 per cent., or one-half. Hence by lowering the water 10 per cent. only one-half the weight of wet peat that would have to be dug before the reduction has to be dug out and handled for a given weight of finished product.

Drainage may be unnecessary, or even undesirable, where the peat is to be dug and transported from the bog to the factory by machinery, especially if it is to be dug by dredges, loaded on scows, and towed in them across the water-filled openings already made to the factory. It would be still less desirable to drain where the peat is to be dug and moved from the bog to the factory by powerful rotary pumps, such as are employed on the "sand-sucker" dredges so often used to improve waterways and harbors in the United States.

Before draining is decided upon as a policy in any given instance the possibility of draining the deposit must be determined. Peat that fills basins formerly occupied by ponds and lakes can be drained only for a short distance below the surface, or not at all, except at great expense, as the outlet must sometimes be lowered for a long distance. An attempt to drain peat beds of this type more than a few feet by surface ditching will, therefore, be unsuccessful, and peat will generally be most easily and most cheaply worked without any attempt at draining unless diking and pumping are adopted. Deposits of this class, as they lie chiefly below the water level and can not be drained, must manifestly be worked almost entirely by machinery, unless the water is kept down by pumping or by sinking tubular drainage wells to porous beds in the ground below the basin, as may sometimes be done.

In bogs filling basins, ditches should not be cut from the shoreward margin to open water in the interior of the marsh without very careful leveling across the surface, because not uncommonly the surface of the water in the pond is higher than that in the marginal area and water will flow from the pond and not into it.

Choice of Site For the Plant.—The choice of a site for the plant would seem to be a simple matter and not of sufficient importance to merit much discussion, but when it is remembered that from 80 to 90 per cent. of the material brought to the plant is water (and therefore waste) it becomes evident that by reducing the distance of the average haul of the wet peat a material saving in the cost of this transportation and production will be made. The permanent buildings of the plant, therefore, should be so placed in relation to the bog to be worked that the raw wet peat will reach the grinding machinery by the shortest and most direct route; from the grinding machinery it should be taken as directly to the drying grounds or sheds.

An ideal arrangement, especially in the manufacture of machine peat, is to have no fixed buildings, but to have the movable machinery always at the side of the openings from which the peat is taken, and to pass the peat directly from the mechanical excavator to the pulping machinery and thence to a part of the bog near by that is laid out as drying ground. To insure such mobility of plant, the machinery may be mounted on a strong car and moved on iron rails or upon rollers or broad-wheeled trucks; the engine is used to run the plant and as a locomotive. This is the common practice in many parts of Europe. The plant is much the same temporary sort of an arrangement as a portable sawmill or thrashing outfit. The most recent practice in Germany, Canada and the United States is to combine digging, macerating, and spreading machinery into a single self-propelling plant which is supported on a single platform with or without rails.

However, in some cases it will be desirable to place the machinery on solid ground, because there are difficulties in moving peat machinery of large capacity from place to place on the soft and unstable surface of the wet peat. If the moving of the wet peat is the ruling consideration, the plant ought to be placed as near as possible to the bog, the necessity of a firm foundation and convenient approaches and drying ground being also observed; the hauls necessary to get the freshly dug peat to the buildings should average as short as possible during the life of the plant. The best location would ordinarily be about midway of one of the long sides of the deposit.

Laying Out the Plant.—Several factories in the United States have been built for making peat fuel in which, seemingly, no thought or care has been given to laying out the plant so as to secure the greatest efficiency from the machinery and economy in the details of production. This is evidently a radical defect in such plants, if the highest financial returns are sought, as these are dependent upon successfully solving the following problem, stated in terms of the unit of production. The problem in peat-fuel manufacture is so to handle a ton of wet peat (containing 90 per cent. of water, nearly all of which is useless) as it is dug from the undrained bog that the approximately 225 to 250 pounds of salable materials (containing 12 to 20 per cent. of water) which will be obtained from it can be sold in the open market at a price that will pay for the digging, preparation for sale, and cost of selling, and, in addition, maintain the plant and equipment and return a profit on the investment. The handling of many tons of this wet raw material and the production of a large amount of marketable fuel only complicates matters if the unit of quantity is made at a loss, and manifestly any saving in the course of proper preparation will help to give a favorable solution of the problem.

The machinery should be so arranged in the building that its best operation requires the least possible labor and supervision and that the various processes through which the peat must be put will become automatic or go on with the minimum amount of human labor and attention. Careful study should be given to the entire course of production and whenever simple and efficient machinery can be substituted for manual labor, it should be introduced, if possible.

Selection of Process and Machinery.—The process by which a given peat bed can be utilized to the best advantage and with the greatest profit depends, among other factors, upon the quality of peat, the kind of market which can be reached, and the amount of capital which is available for the purpose. Not all kinds of peat will make good briquets, even with the best machinery, and it would be a needless expense to erect a large and expensive plant in a region of limited population, or where coal or other fuels are very cheap. It would obviously also be a poor policy to choose a process which would need a large investment of capital when an equally salable type of fuel, whether actually as good or not, could be made with a much smaller investment. It should be remembered that there is no such thing as a really secret process for making peat fuel, that when the time comes for selection the number of available processes is not large, and that all such processes have often been described by European authors or by others discussing the use of peat in Europe.

It should be the chief concern of the purchasing agent before any decision is reached to learn everything possible about the progress of peat-fuel production in Europe, and especially in Germany and Sweden, where, for more than a century, experienced men with keen, well trained minds and ample facilities have been studying the possibilities of the substance and have been testing ways in which they have thought it could be most cheaply and readily made into an efficient and salable product.

After obtaining this information a careful examination should be made of the kinds of machinery now on the market as the practical result of the world's experience. That type should be chosen which has proven most efficient and successful in actual operation under conditions similar to those under which the proposed plant is to operate. With so many available types that have been thoroughly tested by commercial use it is not advisable to adopt new and untried processes and machinery for a plant that must be made financially successful from the start.

Cost and Size of the Plant.—The size of the prospective operations, the process of manufacture chosen, and the amount of capital to be spent will govern to some extent the necessary expenditures for buildings and machinery. Aside from these factors, however, expediency and the actual needs of the business should govern the character of the buildings.

The permanent buildings needed for a factory making machine peat are few and can be of the simplest and cheapest construction consistent with durability for the expected life of the plant. All that is actually required is sheds for the protection of the boiler, engine, and grinding machinery and for drying and storing the peat. As production is limited to the warm months, heating and lighting in the winter do not have to be considered. This fact may also be taken into account in the construction.

In Europe many establishments making peat fuel have no permanent buildings, except for storage, as the machinery is all movable and is given temporary housing at the places on the bog where it is in use. Each peat machine makes a certain number of tons per day and the plant is added to by the purchase of new units as the need for increased output arises. The same would be true if self-propelling automatic machines were used instead of the standard older types.

If peat briquets are to be made, somewhat larger and more substantial buildings must be erected, because more machinery of heavier construction must be housed; yet even for the briquet plant the buildings may be built as cheaply and roughly as sawmills. The chief requirements are that the roofs keep out the rain and that the foundations for the presses, boilers, drivers, and engines be of sufficient strength. A simple, inexpensive, compact, and well arranged plant of moderate capacity, increased unit by unit, is much more advisable than large and costly buildings containing small equipment.

Peat coke, or charcoal manufacture combined with the recovery of by-products, requires a heavier investment for buildings to house the much greater quantity of apparatus necessary, and these must be of good construction, because the plant will be operated the entire year. Practically the same statement applies to the buildings that would be needed for utilizing peat for gas production. Even for such uses, however, care may be exercised to keep down the outlay of construction by making the necessary buildings simple and inexpensive. Some of the buildings which have been erected for peat-fuel factories are monuments to the dreams of their builders.

Capitalization.—The capitalization of peat enterprises, as stated in the preliminary literature issued by their promoters, has varied greatly. At least one reported an authorized capital of $20,000,000. Obviously, however, certain definite matters control the sums of money which must be provided to establish a plant for using peat and to bring it to a successful stage of production, and these are here considered. In general, it may be said that large capitalization is neither needed nor desirable for most forms of peat utilization, but it is important, as has been noted above, to have reserve capital for use during the critical periods of the proposed factory. The amount of capital actually needed will differ for different products and for different ways of making the same products; it will be governed also by the proposed quantity of output, the size and kind of buildings to be erected, and other factors which do not need to be taken up here. The simpler processes of peat-fuel making on a moderate scale can be undertaken and carried on with success on a small capital. Some of the more complicated operations, such as making peat coke and by-products, or those peat products requiring heavier machines, more manipulation and labor, and stronger and more expensive buildings, must be liberally supported with money or credit if any returns are to be derived from them.

A much greater amount of capital must be assured and actually paid in, as required, to bring to a commercially productive and independent stage a plant that is equipped with machinery invented to exploit some new way of treating peat than would be needed to do an equivalent amount of development with machinery that is already on the market and has proved satisfactory in actual manufacture of the product which it was designed to make. This statement is warranted by the experience of many of the more aggressively advertised experiments in peat development which have been made in America and Europe. These experiments have invariably taken much more money and time to bring to a state of completion than their inventors anticipated; and some, after all have failed.

Experimental Work in New Plants.—The past uncounted waste of time and money in this country in what is called experimentation demands a brief notice. Experimentation has generally signified the random use of the whole or a part of a plant and its force of laborers for the purpose of testing some of the ideas of the man in charge or of some of his associates, in the hope that the process or machinery in use may be advantageously supplanted. The futility and waste lie more in the way in which the work is generally carried out than in the ideas themselves. Usually experimentation of this sort is attempted without the appliances for exact methods and without the originator having any clearly developed plans as to what is needed or how the work is to be conducted; yet it calls for much energy and money, and in the end counts for nothing. If the same amount of work and funds were used to raise the efficiency of the working force and of the machinery already in use, much of the experimenting would be entirely unnecessary. Sometimes the men who propose the changes are entirely without experience and training, or have only elementary knowledge, and the work which they do is nearly all lost. It appears certain that the men who have come nearest to success or have had the greatest success in making peat fuel have done so by avoiding as much as possible the expense of the sort of experiments described. They have developed their plants to profitable production by learning in practice from day to day the peculiarities of the substance with which they worked and the conditions required for making the best product possible with the machinery and process which they had chosen.

It must not be understood that properly controlled and carefully planned experiments may not lead to valuable results in the making of products from peat, but in so far as this work is done by inexperienced and untrained men, and diverts time, money, energy, and work needed to improve the commercial operation of the plant, it is a source of injury and positive loss, and may destroy what would otherwise be a profitable business.

It may be said in closing this discussion that in the writer's judgment the adoption of untried machinery for peat manufacture should always be considered as a purely experimental or speculative investment, especially if only working plans and calculations are submitted as the basis of the proposed plant. Only that machinery which has been actually used and has shown what it will do under approximately commercial conditions should be the basis of a factory from which it is necessary to get quick financial returns.

PEAT AS FUEL.

In Ireland, England, Denmark, Germany, and the other countries of Europe where peat is a common domestic fuel, the simplest and most ancient method of preparation is still most commonly used. In Ireland, where nearly all the fuel consumed by the country people is peat, no other process of preparing it has ever been used to any appreciable extent. Within a few years, however, the Department of Agriculture and Technical Education has established several temporary experiment stations for the purpose of introducing to the people the treatment of peat and its manufacture into fuel by simple machinery, most of which is of German origin.

CUT PEAT

The preparation of cut peat and the equipment for making it are so simple that the owners of small peat deposits can easily make fuel for home consumption. On this account a somewhat detailed description of the methods of procedure is given here, although the product is such that probably it can have only a very limited use in the United States.

After the surface of the part of the bog that is to be used is cleared, it is drained to the nearest watercourse by a ditch of good size. Into this main ditch are led a number of smaller ditches of sufficient capacity to lower the general water level in the peat at least 2 or 3 feet.

The part of the field to be worked is then chosen and more carefully cleared and leveled, so that its surface may be used as a drying ground. If this area is selected near the margin of the main ditch, it will be more easily and cheaply drained than if it is at a greater distance, because the water will already be lowered there, and the transverse ditches when dug will be as short as possible. Such small transverse ditches on the drying ground are made about a foot wide and with enough slope to the bottom to carry off the water that collects in them; they are generally placed from 30 to 60 feet apart.

If the bog cannot be drained cheaply by ditching, an opening may be made near the place selected for beginning work. The water can be pumped from this opening from time to time as it accumulates and can be conducted away from the immediate vicinity of the hole and the drying grounds. Care should be taken not to let water into such a hole by digging into the sands below the peat.

The tools used for making cut peat in different European countries are somewhat different in size and shape, but they are always of the simplest form and construction and differ only slightly from those used in ordinary ditching and digging. In Ireland, the most important special tool is the slane, a stout narrow spade having the length and width of the bricks to be cut. It has a narrow sharp steel lug welded on one side of the point of the blade and at right angles thereto. Some types of spades used for peat cutting in Germany have two of these lugs, one in the middle of the blade and the other at one side, so that two bricks can be cut at once. The size of the bricks varies in different countries according to the purposes for which they are to be used, the moisture conditions under which they must be dried, and the density and structure of the peat. The usual range is from 8 or 10 to 18 inches in length, and from 4 to 7 inches in width by 3 to 6 inches in thickness, when the bricks are freshly cut and wet.

The men generally work in pairs, a digger and a tender. The turf is first removed from a strip at the end of the ground prepared for digging and the peat below dug out in the form of bricks of as nearly uniform size as possible, and placed to one side. The tender picks them up, loads them on a car or wheelbarrow, wheels them to the drying ground, and lays them out for drying. As soon as the peat has been removed from a depth twice the length of the spade, or, more often, to the depth of the ditch bottoms, a new cut is started, the digger working in the trench to make the horizontal cuts, which are the last ones to be made. The vertical cuts are made with a straight spade or spade-like knife, the operator first making the wall cut at the length of the block from the last cut. The cuts forming the sides of the blocks are then made the width of the block apart; the horizontal cuts are made from the trench, and determine the thickness of the block.

If the peat is very thoroughly decomposed and structureless, the blocks may possibly be cut with the long axes vertical, using the slane, but where stratification is well marked or the peat fibrous this way of cutting causes the blocks to be easily broken along the lines of bedding; hence in most cases the length of the block is cut parallel to the planes of bedding. The slane may be used to cut the bricks out after the first vertical cut is made along the wall, especially where the peat is dense enough to be cut easily.

After the blocks are taken to the drying ground they are stood on edge, with narrow spaces between them, and allowed to dry and drain for some days; in some countries they are turned during this time. In

Ireland as soon as they are firm enough to be handled they are "footed," or stood on end, generally seven in a small circle and two others crossed on top of the group.. After a week or two, in good drying weather (or longer in bad weather), the blocks are "refooted" by turning them and combining two piles into one. In about four weeks they are ready to be removed and stacked. The bricks are piled in an open manner so that the air can circulate freely through the piles, and the peat is often left in these stacks until needed for use, the top being protected by a thatch or by a shed roof. If dried too rapidly, the product cracks and is brittle, and in this country stacking to check the drying may have to be resorted to in less than four weeks. In different countries the methods of piling the still moist peat blocks vary somewhat, but any open form that gives free access of the air to as much of the block as possible will serve. Where lumber is cheap, racks similar to those used in brickyards may be used to advantage for the preliminary drying and will hasten it by some weeks.

Peat blocks of the sizes given weigh from about half a pound to a pound and a half when they are air-dry or contain from 15 to 30 per cent. of moisture.

The cost of producing peat in this form varies with the cost of labor and the skill of the laborers who do the work. In Continental Europe, where this sort of work is usually paid by the piece, the men getting a fixed price per thousand bricks in each of the processes of digging, spreading, etc., the fuel is made at from 50 cents to about $1.75 per ton of air-dry peat bricks. The efficiency and price of labor and the different ways of handling the product are the only apparent reasons why the price should greatly vary. Cutting and drying peat for fuel should be done as early in the season as possible, because the product dries much more quickly in spring and early summer than later, and when the gathering is put off till August the peat may not get thoroughly dry before winter.

Cut peat is the poorest form of peat fuel, as it is bulky, friable, and burns up rapidly with considerable waste when thoroughly dry. In general, this kind of fuel may be considered as unfitted for American fuel markets; its chief use, if any, will be in the homes of its producers. The dark-colored, thoroughly disintegrated peats make the best cut bricks and the light-brown, fibrous kinds the poorest, except for kindling.

In some parts of Europe, however, cut peat is still used to a considerable extent, even in the towns. Where it is made on a large scale machines are used to dig the peat, as these give the advantage of producing large blocks quickly, even from undrained and undrainable bogs which could hardly be worked by hand.

The essential part of such machines, which differ mainly in the details of construction and not in principle, is a series of three vertical iron or steel plates edged with steel knives. These plates are arranged in the form of a bottomless box from which one side has been removed and are supported and moved by simple machinery. The knives are forced into the peat to the desired depth by a strong rack and pinion operated by a crank turned by hand. The column of peat thus formed is cut off and supported at the bottom by a horizontal knife that is forced across the bottom of the box formed by the three vertical knife-edged plates. The horizontal knife is operated by a powerful lever worked from the surface. The column of peat, held up by the horizontal knife, is then raised by reversing the motion of the crank, and as it is brought above the surface it is cut into bricks with a spade, just as when cut by hand.

Some machines of this type will cut peat to a depth of more than 20 feet. They usually can be operated by two men; one raises and lowers the cutting apparatus and the other cuts up and loads the peat on barrows or cars, in which it is wheeled to the drying grounds. Where the peat is cut from considerable depths by large and heavy machines, three or four men may be needed to each machine. Peat-cutting machines of this sort are strongly built, but may be moved from point to point on the surface of the bog as digging progresses. The guide for the knife can be moved so that a trench several feet wide can be cut without changing the position of the whole machine.

MACHINE PEAT

The term "machine peat" following German practice, has so generally come into use to designate peat that after being dug has been treated to a process of grinding or macerating and pressing before forming it into bricks that it is used here. Terms which are nearly or quite equivalent are press peat, pressed peat, condensed peat, machine-formed peat, and wet-process peat, so-called in the United States to distinguish it from briquetted peat, which is thoroughly dried before being formed into blocks by great pressure in a briquetting press.

Cut peat as a fuel that is to be used, or even produced, on any considerable scale has well-marked defects, such as lack of uniformity, firmness, and density, small fuel value per unit of volume, and a high percentage of water frequently found in it even after prolonged drying. These defects led to early efforts to work the raw material into a more compact and durable form which would dry more thoroughly and quickly and would be more dense and therefore easier to transport. By the effects of the mechanical treatment mentioned above, the plant remains in the peat are reduced to a fine pulp, and their water-retaining capacity is lowered considerably; hence peat that has been thoroughly ground and mixed dries more quickly and forms denser fuel than that untreated. Within limits the more thorough the grinding and pulping and the more quickly the drying takes place, the more compact is the resulting fuel and the better its quality.

In theory, at least, when peat has been thoroughly macerated, a block of it is soon covered by a thin coating of a colloidal or glue-like material, which becomes nearly waterproof on drying, but which is sufficiently porous to allow moisture to pass through it from the inside of the brick. Possibly also this coating, when wet by rain, absorbs enough water to close up the minute openings which exist in the surface when it is dry, and thus prevent further absorption. Hence after a heavy rain properly ground machine peat is nearly as dry as it was before, whereas cut peat takes in a large amount of water, and if the rain is prolonged may be much disintegrated. At the same time the contraction of the outer layers of the brick as they dry out exerts a certain pressure on the water contained in the interior, and thus probably forces it out toward the moister side, which in this case is always the one lying on the ground or on which the brick is supported.

In considering the development and construction of a factory for making machine peat, the following processes must be provided for: Digging the peat, transportation to the machine, grinding, removal to the drying grounds or sheds, care during drying, and, usually, subsequent stacking and storage. If, as is often the case in Europe, the peat machine is placed on the bog at or near the opening from which the peat is dug, the second process is eliminated, as the material may be dug and placed in the machine by one operation, either by hand, by a dredge bucket, or by a mechanical digger and elevator. Digging, macerating, and spreading form a continuous, automatic operation in the latest types of self-propelling, portable plants now being tested in America and Europe.

Types of Machines. — The most recently devised and efficient form of this class of machines has a hopper for receiving the peat at the inlet end, doors in the outer casing, by which all working parts can be easily reached, and a device for cutting the strand of peat pulp into bricks of uniform length as it issues from the orifice. In some models the vertical body is still retained, in others there is a combination of vertical and horizontal cylinders. In some machines the knives are separate from the screw flanges, but mounted on the same shaft with them; in others the flanges of the screw are sharpened and work against stationary knives set fast in the cast-iron walls of the cylinder; still others have both fixed and movable knives, the cutting edges of which work together like the blades of a scissors; a few models have been built and placed on the market, with two knife-armed shafts revolving in opposite directions. Many types of peat machines have been patented in the United States, but few of them have ever been really used, and most of them follow European models.

European manufacturers make peat machines in all sizes. The smallest are run by the power furnished by a single horse, and with the help of a few men turn out 3 or more tons (air-dry weight) of peat bricks per day. The largest must be equipped with powerful engines and accessories and require the services of from 15 to 25 men and boys to dig the peat and handle the 60,000 to 80,000 peat bricks, amounting when dry to 50 or more tons of fuel, made in a successful day's run.

A few excellent models of peat machines are advertised as manufactured in the United States; from among them all a form to meet almost every need can be found. In Ohio one type is made by the Commercial Artificial Fuel Co., 8 Marine Building, Toledo, Ohio, and another by the Buckeye Traction Ditcher Co., Findlay, Ohio.

The principal types of European peat machines of modern construction are fully described and illustrated in a recent publication of the Canada Department of Mines[1] to which the reader is referred for further details. Reference to Bull. 16, U. S. Bureau of Mines, pp. 89-100, and to the catalogues of the manufacturers in this country and Europe is also suggested.

Advantages of a Compact Plant. — The advantages gained by confining all operations as closely as possible to the surface of the bog must not be overlooked. If grinding, handling, and drying operations are all kept as near as practicable to the place where excavating is going on and the finished product is all that is moved away, the waste, chiefly water, is left on the bog and the moving of the greater part thereof is avoided.

In making plans for equipment it is clearly better to install a small complete plant, with only necessary buildings of cheap construction, than to equip inadequately a large plant housed in expensive structures. It should be kept constantly in mind that the output of a well arranged small plant can be practically doubled by duplicating a part of the machinery, but that a small output from a large machine, with too little power and too few accessories, can be obtained only at a considerably greater cost per ton than from the more complete installation.

Cost of Plant. — The investment necessary for equipping a plant for making machine peat manifestly will be governed by the output of fuel contemplated, the number, size, and kind of buildings which are projected, the amount of equipment to be provided for digging and transportation, and the method of drying—whether on the ground or on racks. If the plan of spreading on the ground be adopted, and the peat be formed into bricks by cross marking the peat layer after it has been spread from movable troughs, much of the cost of tramways, cars, and pallets will be avoided. Although this plan is in use, it has not been fully described, and details will have to be worked out experimentally which will necessarily detract from its value when immediate production must be assured.

The following tables of costs have been furnished by manufacturers

[1]Nystrom, E., Peat and lignite; their manufacture and uses in Europe; Canada Department of Mines, Mines Branch, 1908.

of peat machinery. The estimated cost of peat-fuel plant, fully equipped with machinery made in the United States, the fuel to be dried in the air, and the average output to be 50 tons of finished product per day, will be from $20,000 to $25,000, as follows:

ESTIMATED COST OF PLANT FOR A BOG THAT CAN NOT BE DRAINED.

1 dipper dredge	$5,000
6 scows, at $250 each	1,500
1 scow excavator and elevator for unloading scows	1,000
1 factory building and power house	2,000
1 boiler (100 horsepower) and engine (75 horsepower) and installation	1,800
1 heater, pump, and fittings	300
1 peat machine and accessories	1,500
Pallets, trucks, and railroad tracks from building to drying grounds	2,500
Drying sheds and racks	3,000
Storage bins and scales	2,500
Miscellaneous machinery, tools, railway sidetracks, etc	1,000
Blacksmith and carpenter shops, tools, etc	500
Bog, 100 acres, at $20 per acre	2,000
	$24,600

Such a plant could be increased to 100-tons daily capacity at a small additional outlay.

For a bog that is or can be drained, and has a comparatively level bottom, the dredge could be replaced by a forward-end or side continuous-bucket excavator costing $3,500.

Tracks and hopper-dump tram cars for this equipment would cost about the same as scows, and a pump and power to run it would be needed to keep the excavation clear of water

A plant with an estimated capacity of 25 tons of finished peat fuel per day will cost about one-third less than one of 50 tons capacity.

A portable plant with estimated capacity of 20 tons of finished product per day can be installed for from $5,000 to $7,500. The peat machine, boiler, engine, and digging machinery for this size plant are all installed on a large, broad truck running on a portable wide-gauge track. The costs are divided as follows:

ESTIMATED COST OF A PORTABLE PLANT.

1 truck	$1,000
1 20-ton peat machine	1,350
1 mechanical digger	250
1 boiler and engine	750
Pallets, cars, and track	1,500
Miscellaneous tools and equipment	250
1 drainage pump and power	250
	$5,350

These estimates are for maximum cost, and can doubtless be reduced in many ways by taking advantage of local conditions. Trackless self-propelling combined digging, macerating, and spreading machines, capacity from 20 to 75 tons per day, are estimated to cost from $5,000 to $25,000 each.

Price of the Bog. — Still another factor to be taken into account is the price of the bog to be utilized. Little discussion has been given this matter because undrained peat land in the greater part of the United States is held at a very low price per acre, often merely a nominal value being placed upon it. The question may rise, however, as to the maximum figure per acre that could be paid for the bog if the peat was to be dug and manufactured into fuel or other commercial product. If the peat is of good quality and has an average depth of 5 feet, at least 1,000 tons of air-dry peat fuel can presumably be made from each acre. Hence, if $50 per acre is paid, the cost of the raw material will be 5 cents per ton; to this must be added the interest charges on the unused portions of the bog. These charges may be entirely offset by clearing and using a part of the bog for growing certain kinds of crops, as is often done in Germany. Apparently, however, good or even bigh prices can always be paid for suitable and accessible bogs without imposing too large a charge for raw material upon the finished product.

Probable Output From a Small Plant. — During the season, from the middle of March to the middle of October, a peat machine of 25 tons daily capacity should make at least 3,000 tons of finished, dry fuel in nearly any part of the United States, and in Ohio in favorable seasons the output might easily be 500 or 1,000 tons greater.

Such a machine would be much easier to operate at its full capacity, and to provide with full accessory equipment, than one of double the output. Unless the market for the product is known exactly beforehand, planning on a small rather than on a large scale is doubtless much better. The small, well planned, and thoroughly equipped plant can manifestly be more easily made successful from the outset than can a large and efficient machine, for which necessary accessories are planned in the future, but which, for the present, must be made to run with poor and insufficient equipment.

Cost of Manufacture. — It is generally stated by those who discuss the question that machine peat may be prepared for use at a cost not exceeding $1 per ton. Doubtless this is possible, if only the actual cost of handling be considered, as in Europe, where the cheapest labor is used in the manufacture of peat; the expense for labor in its preparation is generally stated to be below 75 cents per ton. If, however, the reports of test runs and of carefully managed companies be examined, it will be found that, even in Europe, when the entire cost of production is reckoned and the proper charges for raw material, management, selling, maintenance, interest, etc., are made, the estimated expense is often doubled. Hence it is not improbable that even under favorable conditions the entire cost of making fuel by this method will be more than $1.50 per ton, and will often run as high as $2 or more if all the details of the business are not closely watched. In one instance in the United States, however, a report was made that the entire cost of digging by machinery, drying, and gathering was about 60 cents per ton of product, but the peat was not formed into bricks, but was spread and gathered by machinery. In another instance a cost of less than $1.50 per ton of dry fuel is reported where the peat was dug by hand.

Selling Prices.—Eventually the real or supposed value of a product, the supply and demand, the cost of production and transportation, the competition of similar substances, and the extent to which it can be monopolized, are among the factors which settle its price in open market.

At present it is difficult, if not impossible, to predict the prices that machine peat will command in the United States when once it is an established staple in the fuel market. The small quantity that has already been made and sold has been eagerly taken at high prices, often seemingly out of curiosity, but after trial more has been asked for, and no complaints have been made as to the price. A recent report from one of the larger cities stated that a dealer in fuel had asserted that he could sell a number of thousands of tons of air-dry peat bricks at $4.50 per ton if he could get them to sell. Five dollars per ton is frequently mentioned as the retail selling price, even in competition with cheap bituminous coal. In Canada the Department of Mines reported the demand for peat fuel in 1910 to greatly exceed the supply. That such a price will be maintained where the product is to be used for commercial boiler firing or for manufacturing purposes is hardly to be expected, but the wholesale selling price would probably fall to $3 per ton or below. If, however, the cost of production is kept down as it should be and the production of fuel is large enough, the last-mentioned price offers a good percentage on the investment necessary to make the commodity. Where the manufacturer is so well placed that he can utilize his men and teams during unfavorable weather and after the producing season is over by conducting a retail business, he can command the highest price attainable in his market. This would apparently be good practice, as it would make feasible the employment of some of the men for the entire year.

Artificial Drying.—A system of artificial drying is an ideal of those who have been working on the problem of the sure production of a large amount of peat fuel in a given time from a single plant. Even recently the statement has been made that no considerable quantity of peat fuel could be produced in North America unless artificial drying could be assured, and more than one attempt has been and doubtless will be made in the United States to develop plants so planned that the raw wet peat as it is taken from the bog can be put in at one end of a series of machines and turned out at the other as a dry, marketable fuel, the process being continuous and taking but a few hours.

The table following shows the weight of water that must be evaporated from a ton of peat as its water content is lowered, by 10 per cent. stages, from 90 per cent. to 10 per cent.

WEIGHT OF WATER EVAPORATED FROM A TON OF PEAT AS ITS WATER CONTENT IS LOWERED, BY 10 PER CENT. STAGES, FROM 90 PER CENT. TO 10 PER CENT.

Percentage of water in peat.	Total dry-peat content.	Water content.	Water evaporated for each 10 per cent. reduction.	Residue left for each 10 per cent. reduction.	Total amount of water evaporated.
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
90	200	1,800.0	----------	2,000.0	----------
80	200	800.0	1,000.0	1,000.0	1,000.0
70	200	466.7	333.3	666.7	1,333.3
60	200	300.0	166.7	500.0	1,500.0
50	200	200.0	100.0	400.0	1,600.0
40	200	133.3	66.7	333.3	1,666.7
30	200	85.7	47.6	285.7	1,714.3
20	200	50.0	35.7	250.0	1,750.0
10	200	22.2	27.8	222.2	1,777.8

It will be seen from the above table that eight-ninths of the water in a ton of wet peat is evaporated in reducing the water from 90 per cent. to 50 per cent., whereas 1,000 pounds, or five-ninths of the whole, disappears in reducing it from 90 per cent. to 80 per cent.

It is manifest, also, that only 250 pounds of peat containing 20 per cent. of water will be left as the result of all the processes and labor by which a finished product is made from the ton of wet material.

Peat that has been dried by exposure to the air until it contains less than 50 per cent. of moisture may possibly be dried for fuel, by artificial heat, on a commercial scale, to the air-dried state, by some of the simpler and more efficient types of driers used in other industries, because the certain and rapid completion of the drying at that stage may offset the cost of the fuel used and on the additional handling and plant required.

It is less practicable to artificially dry peat with a high water content down to 50 or 60 per cent. moisture, because the much greater weight of water to be handled and evaporated in proportion to the quantity of product to be recovered requires much more heat than is needed to reduce the moisture from 50 per cent. to the air-dried state.

In the eastern United States the amount of moisture in completely air-dried peat rarely exceeds 15 per cent. and may be as low as 6 or 8 per cent.; it varies as the moisture in the air varies.

From the facts given and also from the requirement that all costs in any system of artificial drying must be borne by the product, it is apparent that the problem of artificially drying peat is decidedly complex and can be worked out only by those who have had special training and experience in designing and building drying machinery for similar purposes and fully appreciate the difficulties involved in this class of work. Any plan to be successfully incorporated in machinery for completely freeing freshly dug peat from its high percentage of water must provide for the utilization of large quantities of waste heat or of fuel that has no other economic uses.

PEAT POWDER

There seems to be a much greater possibility of artificially drying peat in the form of powder or small fragments than as machine-formed bricks, because such material can be handled in much smaller space and more rapidly and cheaply than can the bricks. The small particles also dry more quickly and are not injured by warping, cracking, or by becoming brittle. The peat will dry more rapidly if thoroughly macerated before it is put into the dryer than if it is used as dug.

Although the fundamental factors involved in drying peat by artificial heat are not much more favorable for producing peat powder than peat bricks, the possibility of making the continuous process a commercial success seems considerably greater for the powder than for the bricks. This opinion is held because the cost of equipment can be made considerably less, heat can be applied more directly, and the expenses for handling the product in powdered form can be reduced materially at all stages after it leaves the peat machine. Moreover, the production of dry peat as powder can be assured at any season of the year, as freezing would scarcely injure it at any step of its preparation. In fact, the powdery condition induced in all types of peat by continued freezing and thawing would then be desirable and would naturally be adopted as one of the preliminary stages of the process.

Because peat is readily reduced to a powdered form, has a larger percentage of volatile matter than coal, and burns with a hot flame, it is well adapted for use in powder burners. For this purpose the peat does not need to be crushed as fine as coal because of its more porous structure, which permits the penetration of air, thus insuring complete combustion. It also ignites at a lower temperature than coal.

It is well known among users of fuel that various types of familiar materials are now burned as powder by the use of specially designed blast burners. Sawdust and powdered coal have been used for a number of years in burners of this type, and most satisfactory reports have been made by the users. The claims are made that the combustion with this form of firing is so complete that there is no black smoke from coal, that the efficiency of the fuel is increased, and that much less attention is required than when drying is done in the ordinary way. The use of powdered coal has passed beyond the experimental stage in Portland cement manufacture and in firing boilers in Europe and the United States. Manufacturers of the improved forms of powder burners claim, for a given type of coal, an increase of from 15 to 20 per cent. in efficiency over common grate firing, and facts seem to warrant the claims.

Such burners can be regulated for automatic fuel feed, for furnishing the proper amount of air, and for blowing the fuel into the fire box, where it burns almost exactly like a gas. For further details the reader is referred to Bull. 16, U. S. Bureau of Mines, pp. 112–116, and to the work of Nystrom[1] and Ryan.[2]

PEAT BRIQUETS

Manifestly peat powder can not be burned economically in an ordinary fire box or stove, because it packs so that no air can get through it, or it falls through the grates if stirred. Such fuel is also open to the objections that are urged against other forms of peat fuel, and is costly to transport as compared with coal. To avoid these difficulties the proposal has been made to shape the dry powder into briquets by the use of specially designed briquetting presses. In Europe, where peat is commonly used, and where for a considerable time lignite and poor grades of coal have been put on the market in briquetted form, and have found ready and constantly increasing sales, it is not surprising that peat should have been briquetted at an early date.

Properties.—Peat, when briquetted, makes a most attractive type of fuel, as the briquets are uniform in size, may be of cylindrical, ovoid, prismatic, pillow, or other shape, and often have a highly glazed black surface. The briquets are clean to handle; they are also compact and dense, so that they occupy less space, and are more easily transported and stored than the same weight of the same peat could be if in any of the other forms described. They burn less rapidly than cut or machine peat, and hence give less trouble in firing for power production than do other kinds of peat fuel.

It has been pointed out, however, that peat briquets are likely to crack and crumble when handled roughly, and to break down in the fire into a powder, whereas machine-peat bricks burn like a piece of

[1]Nystrom, E., Peat and lignite; their manufacture and uses in Europe, Canada Department of Mines, Mines Branch, 1908, pp. 171-172.
See also Canada Department of Mines, Mines Branch, Bull. No. 4, 2d ed., 1910, pp. 19 and 31 to 44.
[2]Ryan, Hugh, Reports upon the Irish Peat Industries, pt. 2; Econ. Proc. Royal Soc. Dublin, Vol. I, pt. 13, pp. 516, 520.

good coal, or wood, without falling apart. The briquets are also easily wet by rain, and are quickly disintegrated by exposure to storms; therefore they must be stored under cover and shipped by rail in weather-proof cars.

Methods of Manufacture. — In the parts of Europe where peat briquets are made the peat is cut or dug from the bog and is allowed to dry in the air until the water is reduced to about 40 per cent. The peat is then powdered and dried artificially to about 15 per cent. moisture, after which it is briquetted or stored for future briquetting.

The Canadian method of drying peat on the surface of the bog in a thin layer and picking up the dry material at frequent intervals with a vacuum dust collector does away with most of the cost of drying and subsequent handling, so that after a brief exposure to artificial heat it can be satisfactorily briquetted. The process was primarily designed by its inventors to produce at the lowest cost air-dried peat for making briquets.

Types of Presses—The essential part of a plant for making peat briquets is the briquetting press. Such presses are of two general types—the open and the closed mold. In the open-mold type the dry peat powder is introduced into a straight tube, or mold, of circular or other shaped cross section, and compressed by a tightly fitting piston that exerts a pressure of from 18,000 to 30,000 pounds per square inch. Sufficient resistance is offered by the friction of the peat on the sides of the tube to press it into a solid block or briquet, while at the same time the air is forced from the peat. With each stroke of the piston a new charge of peat enters the mold and a finished briquet leaves the outlet end; the briquets already made act as a cushion and, in fact, form the bottom of the mold. The friction is sufficient in presses constructed on this principle to raise the temperature of the mass enough to release some of the tarry compounds of the peat, and these cover the sides of the briquets with a highly polished glaze. A chief objection to this form of press is said to be that the constant heating and friction produce great wear on the molds, and the plates forming them must be removed every few days and reground, so that after a comparatively short life they have to be renewed.

The number of briquets that can be made with such a machine manifestly depends upon the number of strokes of the plunger to the minute. For briquetting lignite, this may be as low as 80 or as high as 130; thus the number of briquets made in a minute lies between these limits. The output of peat briquets is usually about 100 a minute, because the peat powder is sometimes blown from the mold if the press is run at greater speed.

In briquetting presses of the closed-mold type various forms of rollers and plates, or plungers and wheels or plates, or even special forms of crown wheels, have been employed for the two halves or parts of the molds. The advantage claimed for presses of this type is their greater rapidity and durability, but mechanical difficulties are encountered in getting sufficient pressure to make solid briquets aud in keeping the two halves of the mold in exact adjustment. This form of press is sometimes used when a binder of pitch or other resinous or tarry matter is used to cement the particles of fuel together to make the briquets less breakable when handled or burned.

European briquetting presses of the open-mold type are made in three sizes—a small size, turning out from 16.5 to 22 tons of finished briquets in 24 hours; a medium size, having a capacity of 33 to 44 tons in 24 hours; and a large size, which makes from 44 to 55 tons in 24 hours.

To produce a ton of peat briquets costs considerably more than to produce a ton of machine peat because of the greater power required, the artificial drying, and the additional expenses for stronger buildings and more complicated and powerful machinery.

Cost of Plant.—European briquetting presses of 50 tons capacity in 24 hours, which is the size most often considered, need engines of about 100 horsepower, operated by high-pressure steam; in the best equipped European plants the steam is superheated to about 665° F. and the boiler pressure is carried at about 150 pounds. The exhaust steam from the engines is used in the driers, at about 30 pounds pressure, and is returned to the boilers after condensation under about the same pressure.

A briquetting plant, fully equipped with the best types of German machinery, including a drier, will cost two to three times as much as a plant for making cut and machinery peat, even if only a single press with a capacity of about 50 tons per day is contemplated.

At least three distinct presses for briquetting peat have been invented and tried on a factory scale in Canada. Two are of the closed-mold type, although working on very different principles; the third employs an open mold. The peat used for these plants was dried as much as possible on the surface of the bog, but the final drying was done in specially designed rotary driers.

The essential details of these plants have been described by Nystrom.[1] Of these plants only one was operated in 1908, and no figures as to the cost of installation or of the production of the briquets are available. Two of them made a small output in 1910. Several forms of presses of American construction for briquetting coal and lignite, and some designed for peat, have been developed and are on the market, and probably these could be installed at somewhat lower cost than any which have been made abroad. It is doubtful, however, whether a bog can be purchased, proper buildings erected for housing

[1]Nystrom, E., Peat and lignite; their manufacture and uses in Europe. Cadana Department of Mines, Mines Branch, 1908, pp. 148-157.

the machinery and the finished briquets, and the necessary machinery bought for digging, grinding, drying, and briquetting the peat for an output of about 50 tons of briquets each 24 hours for less than $60,000 to $75,000, although estimates as low as $35,000 have been made based on untried machinery.

The plan of drying the peat upon the surface of the bog and gathering it as a dry powder with a small amount of water, because a part of the cost of preparing the peat for briquetting is thus eliminated, should reduce the primary cost of the plant by a certain amount. It is questionable, however, whether the cost of collecting machines and their installation would not be almost as great as that of the rotary driers which they would in part displace. Their operation by electric power might prove to be nearly as expensive as that of steam driers utilizing waste steam.

The operation of the briquetting part of a plant during the winter could be made possible by operating a number of the collecting machines during the favorable months of the drying season and storing in stock piles or storage bins the excess of dry peat as it was taken from the surface of the bog. If storage under cover were adopted, the construction of the necessary buildings would be an added charge.

The following statement, which shows the cost of a briquetting plant with an estimated output of 50 tons of peat briquets per day, is quoted from an estimate furnished by Mr. F. H. Mason,[1] when United States consul general in Berlin, Germany:

Buildings	$14,280
Machinery	17,850
Steam engines and fixtures	3,570
Tramways	3,570
	$39,270

These figures are approximate only and will have to be considerably modified to meet present conditions.

Comparative Fuel Efficiency.—Naturally, the inquiry will be made whether the added expense of equipment and the greater cost of making peat briquets is justified by a corresponding increase in the efficiency of the fuel. Seemingly it is not, because of the cost of production is at least one-third greater than for machine peat, whereas, according to Nystrom,[2] the heating value is increased only about 15 per cent. Actual analyses of peat from the same deposit at Black Lake, N. Y., and prepared in different ways, are given below. The samples were taken at random from considerable quantities of similar

[1]Mason, F. H., Special Consular Reports, Vol. XXVI, 1903, p. 81.
[2]Nystrom, E., Peat and lignite. Canada Department of Mines, Mines Branch, 1908, pp. 147-149.

material which had been given identical treatment, but possibly gathered at different times; that is, the samples were not prepared especially for these analyses.

ANALYSES OF PEAT TO SHOW THE EFFECT OF METHOD OF PREPARATION ON HEATING VALUE OF A GIVEN PEAT.

Lab. No.	Character of fuel.	Moisture.	Volatile combustible.	Fixed carbon.	Ash.	Sulphur.	Heating value.	
							Calories.	B. t. u.
6436	Raw peat:							
	Air-dried	8.68	50.92	23.79	16.61	0.99	4,179	7,522
	Moisture-free	....	55.77	26.04	18.19	1.08	4,576	8,237
6394	Machine peat:							
	Air-dried	9.33	49.85	23.35	17.47	.89	4,055	7,299
	Moisture-free	....	54.97	25.77	19.26	.98	4,472	8,050
6392	Dry powder before briquetting:							
	Air-dried	7.37	52.03	22.74	17.86	.96	4,102	7,384
	Moisture-free	....	56.17	24.53	19.30	1.03	4,428	7,971
6395	Briquetted steam-dried peat							
	Air-dried	8.00	52.19	22.44	17.37	1.16	4,193	7,547
	Moisture-free	....	56.73	24.39	18.88	1.27	4,557	8,203

Average heating value of dry peat, 8,115 B. t. u.

This table indicates that the differences in the number of heat units obtained from the different samples are slight, and it is difficult to see that any appreciable change has been made by the various kinds of treatment. Equal variations might occur in the same number of samples of peat collected from a single stratum at the same time but analyzed separately. Therefore, except for the greater compactness and hardness obtained, there is no justification for incurring the cost of briquetting. However, a larger series of more carefully collected samples may show greater variation than is here indicated; or if drying or briquetting at high temperatures is adopted so that some of the lighter volatile combustibles are driven from the peat, a somewhat higher thermal value may be obtained. Clearly, however, briquetting as a rule increases the number of heat units per unit of volume and not per unit of weight; that is, the peat is made more compact, so that it can be transported and stored in smaller space and burned in smaller fire boxes than if prepared in other ways. Whether the advantages thus obtained are sufficient to justify the additional costs of building a plant and of making the briquets on a commercial scale must be demonstrated by actual operations.

Electric Processes for Drying Peat.—The fundamental plan of electric processes for drying peat is to pass electric currents, either direct or alternating, through the wet peat, with the idea of liberating the water by breaking up the cells and fibers of the vegetable remains in the peat. The most thoroughly advertised of these processes was one developed in England and embodied in two plants, one at Kilberry, near Athy, in the county of Kildare, Ireland, and the other near Eaton Rapids, Mich. Although both of these plants were well supported by capital and equipped with unusual thoroughness, neither was successful.

Wet Carbonization.—In 1904 and the following years Dr. M. Ekenberg, of London, England, conducted a lengthy series of experiments on what has been called the "wet carbonization" of peat. As the term indicates, the wet peat is subjected to temperatures slightly above 300° F. (150°–155° C.), which drive off a part of the lighter hydrocarbons if the heated mass be kept at ordinary pressure. During the heating, however, a pressure of about 150 pounds to the square inch is maintained by the pump which forces the wet peat into the carbonizing apparatus, so that the process really consists of superheating wet peat in a closed receptacle under pressure of about 10 atmospheres. Such pressure is quite enough to prevent any steam from forming at the temperature at which heating is carried on, so that there is no loss of heat units from this source and no volatilization of the hydrocarbon compounds of the peat.

The peat becomes blackened, loses its structural peculiarities, becomes fine-grained, and, it is stated, readily gives up under moderate pressure a considerably larger percentage of water than untreated peat. It is reported that a form of coking takes place, the extent of which is governed by the temperature used during the treatment, the use of higher temperatures giving more complete carbonization. If this is true, as the blackening of the peat would indicate, apparently the matter driven off must be absorbed either by the peat itself or by the water which it contains, as no gases are developed during the process. It is evident, however, that at the temperature reported (300° F.) the process of coking is not carried very far, because only at considerably higher temperatures are volatile carbonaceous matters driven off by dry distillation.

The exact nature of the changes that take place is immaterial to this discussion, however, since the important fact is that a definite change is effected by the treatment which makes possible the quick drying of the peat by artificial heat and pressure. From available reports the process, when it is fully developed, will seemingly be commercially useful and will enable those who adopt it not only to extend the season of operations to early winter, but to produce very hard, heavy, and black briquets closely resembling coal in appearance and, volume for volume, having about the same fuel value as bituminous coal of ordinary grades.

Cost of Briquets by This Process.—The cost of manufacture, including all charges for digging and grinding the peat and transporting it to the factory, and for carbonizing, drying, and briquetting, interest, depreciation, and administration, is estimated, from the results obtained at the experimental plant in Sweden, to be $2 to $2.25 a ton of finished briquets. The smaller cost is estimated for an output of 20,000 to 30,000 tons in a year of about 200 working days. The English company owning the patents covering the processes and machinery estimates that the briquets can be made in a factory turning out 1,000 tons of briquets a day, under European labor conditions, for about $1.50 a ton, after machinery now being experimented with shall have been fully perfected.

The cost of a plant fully equipped with briquetting presses, carbonizers, and all other accessories is estimated by the inventor at about $160,000; or, if production is to be 30,000 tons of briquets a year, at about $225,000, at European prices for machinery, structural work, and labor.

Claims of Inventor.—The inventor claims for this method of treatment that—

(1) The manufacture is independent of weather conditions.

(2) The work can be carried on equally well night and day.

(3) Undrained bogs can be worked without difficulty.

(4) All the processes of treatment may be completed and the briquets made in two hours after the peat is dug.

(5) The fuel produced is always of the same quality. The water content may be as low as desired.

(6) The number of men required for a plant with an output of 100 tons a day is small compared with that needed for the same output of machine peat, as only from 18 to 24 men are needed, chiefly to watch and care for the machinery.

(7) Since the process is continuous and may be carried on independent of weather conditions, an abundant supply of labor can be had without difficulty, because the men will be assured steady work.

Prospective Value of Process.—The various unbiased reports which have been made concerning this way of treating peat lead to the conclusion that it is one of the most promising that has yet been discovered, and if the treatment and machinery are not too costly it may yet become the basis of a successful continuous process, peat-drying, and briquetting industry. No reports have yet appeared, however, showing that the method has been applied in a successful commercial plant, and for that reason the process must still be considered as experimental, some of the important details needing development and embodiment in machinery.

PEAT COKE.

The Ziegler Peat-Coking Process.—In the last decade of the nineteenth century a method of coking peat in retorts was worked out and patented by Dr. Martin Ziegler, a German chemist and inventor. In this method the permanent gases derived from the dry distillation of peat are used for heating the retorts in which the coking is done, and for other operations about the plant. The system also provides for the use of the same retorts continuously, and for the recovery in a most practical way of all marketable chemical compounds as by-products. Three plants of commercial size using this system have been erected in Europe; the first at Oldenburg, Germany, the second at Redkino, Russia, by the Russian Government in 1901, and the third at Beuerberg, Bavaria, in 1904. The last-named plant embodies many improvements, and at the time of its construction was the most complete establishment for making coke and by-products from peat that had then been developed. Each of these plants is built on the unit system, each unit consisting of two vertical retorts about 40 feet high and elliptical in cross section. The lower half of each retort is of fire brick and the upper half of cast iron, covered with thin fire bricks, and the two halves are inclosed in a fire-brick shell. Between the two shells are horizontal fire flues. The whole structure is inclosed by a covering of common brick to prevent loss of heat through radiation. The retorts rest on a cast-iron base and taper down to hoppers, each with two openings, closed by air-tight doors, through which the peat coke can be removed as often as desired. In practice the coke is drawn off once an hour into iron cars with air-tight covers and is kept in the cars till cool. The tops of the retorts have heavy cast-iron doors, to which are attached feed boxes with gas-tight covers, opening inward. By this provision new fuel can be introduced whenever necessary without interfering with the operation of the retorts, so that coking is continuous. The volatile matter is drawn off through pipes in the upper half of the retorts by suction fans and led to condensing chambers; there it gives up a part of its heat to concentrate solutions and dry some of the by-products, the tar and tar water being removed by condensation. The uncondensed gases are returned to the combustion chambers to serve as fuel.

The hot gases from the fires, having a temperature of more than 1,800° F. (1,000° C.), are drawn through the fire-brick flues in the walls inclosing the retorts, and thence to a main flue connected both with drying chambers, in which the drying of the peat bricks is completed, and with the chimney.

Besides the retorts in which the peat is thoroughly coked at the Beuerberg plant, each pair of these is directly connected with a circular retort for making half coke or "semicoke," from low grades of peat by using the heat of the waste combustion gases from the coking retorts. These gases, because they have no free oxygen, and hence can not set fire to the peat, are conducted from the collecting flue of the coking retorts directly into the halfcoke ovens, and are hot enough to thoroughly carbonize the peat without driving off all of the tarry compounds. The resulting product is not as hard and firm as the peat coke, and is lower in carbon and richer in hydrogen, but it makes excellent fuel for heating, as it burns with a long bright flame.[1] The Ziegler plant at Redkino, Russia, is reported to have manufactured this product for fuel for locomotives on the railways of the country, and 1 pound of it is said to have evaporated 6.63 pounds of water in a stationary boiler and 5.76 pounds in a locomotive boiler.[2]

Recovery of By-Products.—A good quality of coke can be made from dense, thoroughly decomposed peat that has been machined and air-dried, but the coke must be manufactured under favorable conditions of market and on a large scale, and, if the best financial returns are expected, the coking must be accompanied by the recovery and profitable sale of the chemical by-products and the utilization of the non-condensible gases as fuel for heating the retorts and for drying the peat preliminary to coking.

By such treatment there can be obtained from peat the following useful substances, of which a more detailed account is given in Bull. 16, pp. 130–138.

(1) Coke, or charcoal, the non-volatile part of the peat, consisting of the fixed carbon and the ash or incombustible mineral solids.

(2) Tar, a mixture of the more readily condensed hydrocarbon compounds formed by the destruction of the complex organic substances in the peat.

(3) Tar water, or, as it is sometimes called, gas water, a solution of a number of the lighter, less easily condensed organic compounds in the water originally present in the peat or formed by the decomposition of original hydrogen compounds.

(4) Fixed gases, a considerable part of the volatile matter given off by peat heated in a retort, which before purification form a mixture of elementary and compound gases, some of which are combustible. The yield of gas varies considerably for different kinds of peat, the less decomposed giving the largest quantity and poorest quality.

That peat coke would find a ready market in this country in the regions where iron ores are mined seems probable, however, as it could be profitably used there to produce high-grade charcoal iron. The manufacture of such iron is now carried on in northern Michigan and the adjacent regions at a great cost for the hardwood lumber that

[1] Nystrom, E., Peat and lignite; their manufacture and uses in Europe. Canada Department of Mines, Mines Branch, 1908, pp. 181-183.

[2] After running for some months with seeming success, the Beuerberg plant closed, and has not been operated since. Among the reasons given for the failure of the plant was the great difficulty, except at prohibitive cost, of drying the large quantity of machine peat bricks before they were placed in the retorts.

is converted into charcoal, although in the same territory, and especially in Minnesota, there are extensive beds of peat that have never been used for any purpose. There should also be a good market for the product as fuel in large cities and in parts of the country where anthracite is high-priced or unobtainable.

Systems for making peat coke have been advertised as originating in the United States, but so far as can be learned only one of them has yet actually been embodied in a working plant. A plant for making peat coke has been reported in operation in southern California, but no account of it has been received and no report can be made as to its operations. In fact, so far as is known at this writing, the Ziegler system is the only peat-coking system so far worked out in a full-sized plant that has operated successfully from a financial point of view, except that at Elizabethfehn, Germany, designed by Dr. W. Wielandt, of which no detailed description has been received.

Peat coke should be produced in the United States by a plant equipped for the recovery of by-products and handling 100 tons of air-dried machine peat per day, at a cost of from $3 to $3.50 per ton of coke, if the by-products are sold at current rates. Included in this estimate are fair charges for digging and air-drying the peat, for machinery, and for all other charges that should be borne by the plant.

The price at which the coke can be sold will probably vary, according to the quality of the coke, the locality in which it is made, the purposes for which it is to be used, etc., but it should about equal that of charcoal, or $6 to $12 or more per ton. As the price of charcoal will continue to advance with the exhaustion of the available wood supply, there is a good prospect for an equivalent increase in the probable price of peat coke, because peat coke can be used not simply as a substitute for charcoal but, if of the best grade, as a superior article.

The experience gained by those who have attempted to make peat coke in Europe points clearly to the fact that the operation is not commercially successful unless the peat is of the best quality and the coking is conducted in such a way as to utilize the heat of the gases from the retorts for various purposes throughout the plant. If the coking is to be profitable the condensible distillates should be saved and made into a series of salable chemical by-products

The amount of capital needed for developing a proper plant for making peat coke is so large that the investment is scarcely justified unless a preliminary attempt is made not only to find a market for the coke, but to learn where, in what quantities, and at what prices the by-products can be sold and, if possible, to have at least a part of the output sold conditionally.

GAS FROM PEAT

A few years ago it was predicted that with the rapid introduction of improvements in lighting by electricity the use of gas for illuminating purposes would decrease. Almost at the same time, however, came entirely new forms of gas burners, in which the light is derived from the incandescence of the oxides of certain rare metals, instead of from that of the carbon particles in the flame itself. In these burners the gas is completely burned and the oxides, in the form of a porous mantle, are intensely heated. Much less gas is used than with the old patterns of burners, and much more light is obtained. In addition the cost of gas was decreased by improved methods of manufacture, so that the price of gaslight, for the candle power obtainable, became much cheaper than ever before.

Accompanying the improvements by which gas could be furnished to the consumer at lower prices came also the invention and popularizing of correctly designed burners, stoves, gas engines, and other apparatus for using gas as a domestic fuel and for the generation of power. The convenience, cleanliness, and efficiency of the fuel more than offset its somewhat greater cost for these uses as compared with wood or coal at the prices that those fuels bring in many localities.

ILLUMINATING GAS.

Excellent illuminating gas may be prepared from peat by distilling it in cast-iron retorts heated from the outside. To secure satisfactory commercial results, however, the retorts for making a given quantity of gas must be larger for peat than for coal, and the outlet pipes must be of larger diameter because the peat gives off large quantities of gas quickly; the condensing apparatus also must be more efficient than that required for coal gas, because of the greater proportion of watery and tarry products.

The distillation of peat for illuminating-gas manufacture must be carried on at a red heat, or higher, in order to decompose the heavier hydrocarbons into permanent gases that will furnish substances to brighten the flame when the gas is burned. To maintain this high temperature, the fire boxes of the retorts must be larger than for making gas from coal, and more fuel must be burned to continue the necessary decomposition of the tars.

If distillation is carried on at temperatures that are too low, the gas contains much carbon dioxide and gives a colorless flame when burned; the percentage of carbon dioxide may reach 25 to 30 per cent. and even more if the peat used is not thoroughly dry when it is put into the retort. The evaporation of the water present lowers the temperature of the gases formed so much that the carbon dioxide developed is not decomposed.

WATER GAS.

In recent years a type of gas known as water gas and enriched or carburetted water gas has been used extensively for illuminating purposes. This gas is obtained by bringing steam into contact with incandescent carbon in the form of coke. The steam is decomposed and its oxygen unites with the carbon to form carbon monoxide, leaving the hydrogen free. The mixture of carbon monoxide and hydrogen burns with an intensely hot but slightly luminous flame. To give this gas, which is nearly identical with the gas from some forms of gas producers, illuminating elements, the heavier hydrocarbons are added to it. A common method of enriching water gas is by injecting naphtha or gasoline into it. The enriched gas gives a bright flame of good candle power. It is the type of illuminating gas supplied in many cities of the United States, as it can be made at much less cost than that obtained by the destructive distillation of coal. Peat, although used to make producer gas, does not seem to have been tested for making the carburetted water gas, but such use is evidently possible.

FUEL GAS.

Gas is now much used as a source of heat for power and other purposes, and is rapidly growing in favor for such uses, because of its high efficiency, cleanliness, and the ease and cheapness with which it is handled.

It is apparent from what has already been said regarding the quality and quantity of gas to be had as a by-product of peat distillation or of coking operations that the subject should prove attractive to the engineer seeking a cheap and unutilized fuel as a source of power and fuel gas. Moreover, it is known, from the unqualified statements of trustworthy, unprejudiced, and competent observers, that peat is being given a thorough trial for power-gas production in several European countries where there is an increasing need for fuel for manufacturing industries. In Sweden, Russia, Ireland and Germany this use has passed to the commercial stage of development.

PRODUCER GAS.

The generation of gas for burning under boilers and for direct use in gas engines places few of the limitations on the process or the gas that are inherent in the manufacture of gas for lighting. The main object is to get as much as possible of the heat energy from the original fuel in the form of inflammable gas, yield and uniform composition being more important than the thermal value to the unit of volume or the proportion of inert gas present. For these reasons the use of retorts has been abandoned as too costly for manufacturing gas for fuel and power purposes. In their place have been substituted gas producers in which the fuel elements of the combustibles, the carbon, both fixed and volatile, and the hydrogen are all used, the entire body of fuel being converted into permanent gas and ashes The process of making gas in a gas producer differs from that of making illuminating gas in that a part of the fuel is burned inside of the producer to furnish the heat necessary for gasification and in that no fixed carbon or coke remains.

Used in this way there is a loss of fuel to the extent that heat units are required to bring about the chemical changes necessary to reduce the solid compounds of the fuel to permanent gases that have the power of combining with the oxygen of the air and thus developing heat. In the gasification of fuel in retorts the loss of heat units is even greater than in the gas producer.

The gas producer differs from a common furnace in that less oxygen is admitted to the combustion chamber and the fuel bed is thicker. In an ordinary furnace the effort is made to have the fuel elements take up all of the oxygen possible, and air is furnished in excess of the supply needed for complete combustion in order that the energy of the fuel may be converted rapidly into heat. In the gas producer only sufficient oxygen is supplied to completely satisfy enough of the carbon and hydrogen units of the fuel to convert the rest of it into permanent gases; in other words, in the gas producer the combustion of the greater part of the fuel is incomplete.

Producer gas, therefore, is obtained by gradually converting solid fuel to the gaseous state by the heat given off from the complete combustion of a part of the fuel. The character and composition of the resulting gas is quite variable, according to the kind of fuel and the type of gas producer used.

The simplest form of gas producer for power-gas generation is a vertical cylinder of iron or masonry, lined with fire brick, having a grate near the bottom, an opening in the top for charging fuel, a smaller opening near the top for the outlet of the gas, and one near the bottom for the admission of air. Openings are also provided at various heights on the sides, through which the interior may be reached for poking the fuel bed, inspecting and cleaning the interior, making repairs, and removing ashes. To prevent the entrance of air except through the proper openings, which are covered by gas-tight doors, the bottom of the producer is placed in a shallow tank of water, into which the ashes and refuse fall, and the charging opening is generally a small chamber, guarded by gas-tight doors at the bottom and top, which prevents the escape of the gas and the ingress of air while the producer is being recharged.[1]

[1]For a more complete discussion of gas producers, and the theory of the formation of gas in gas producers, see Bull. 7, Bureau of Mines, 1911, and Bull. 16, pp. 145-160.

The commercial use of peat in gas producers as a source of both fuel and power gas seems to be successful in Germany and Sweden, fuel gas made from peat having for many years been in use in metallurgical operations, in brick and glass making, and in lime burning.

Gas producers for making power gas from peat are now advertised by several manufacturers of gas engines in Europe, and, as has been previously noted, there seems to be no reasonable doubt that such producers are in successful commercial operations in the countries mentioned. New plants for utilizing this fuel are annually added to those already at work, and in 1912 it was reported that large electric power plants using peat for fuel in gas producers were running in Sweden, Germany, Italy, and England, Ireland and Russia.[1]

GENERAL CONCLUSIONS ON PEAT FUEL.

Fuel Value.—The fuel value of peat as compared with that of coal and wood for firing boilers, furnaces, and stoves has already been discussed at length. The facts presented would seem to demonstrate that although plainly inferior to the best coal in the number of heat units yielded per pound consumed, nevertheless, if prepared in the ways commonly used in Europe peat fuel presents so many desirable qualities, such as freedom from smoke, cleanliness in handling, small ash content, completely and easily controlled combustion, and prospective low price, that there should be a good field for its introduction for manufacturing and domestic uses in those parts of Ohio where peat naturally occurs in abundance.

Utilization of Deposits.—There are many small bogs in the peat-bearing regions of the State which, although too small to warrant the establishment of large plants for the production of fuel, could be utilized to furnish machine peat enough for boiler fuel for a single small factory for many years. They might also furnish the power to pump water and generate electricity for a small community for an equal length of time.

The principal matter to be borne in mind in preparing to exploit a peat deposit in such a way is that the simplest equipment which has proved it can yield the desired quantity of usable or salable fuel is the one most likely to give satisfactory returns either in fuel or money. Every added process of treatment beyond that which is necessary to put the peat into usable form for a specific purpose adds many times to the first cost of equipment and to the practical difficulties of mak-

[1]See also Bull. 4, Bureau of Mines, 1910, 27 pp.
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Nystrom, E., Peat and lignite; their manufacture and use in Europe. Canada Department of Mines, Mines Branch, 1908, p. 227 ff.
Ryan, Hugh, Reports upon the Irish peat industries, pt.2; Econ. Proc. Roy. Soc., Dublin, Vol. I, pt. 13, pp. 524-526.

ing a product that can be sold for enough to pay the cost of preparation and of putting it on the market at a profit.

Producer Gas Plants.—The present state of knowledge seems strongly to indicate that large peat deposits can be most profitably utilized, and the largest percentage of the stored-up energy in them recovered as power, by converting the peat into producer gas and using this gas in properly designed gas engines. The power may be used by factories operated on the spot, or as electric energy may be used at a distance. Large plants, by using by-product gas producers and thus at least recovering as ammonium sulphate the ammonia that is formed during the destructive distillation of the peat, may be able from sales of the sulphate to pay a part of the expenses of the whole operation The by-products process, however, may not be feasible for gas-producer plants of small size, because the cost of installation, maintenance, and supervision are proportionately higher for small than for large plants, and the quantity of by-products obtainable from a small gas producer is not sufficient to keep a recovery plant in operation continuously.

Even without any by-products the use of producer gas presents so many advantages that wherever peat beds are to be used as sources of fuel for power installations of more than 100 horsepower, the possibilities of a producer gas plant should be given serious consideration.

The producer gas plant may also be readily adapted to metallurgical work, to firing kilns for brick, porcelain, lime, and probably for cement manufacturing. It might have a large use in roasting ores and, in a smaller way, in foundries and other iron-working plants, and in reheating and refining steel, copper, and other metals when fuel free from sulphur is required.

Even for boiler plants that could use peat fuel, a gas producer would be a most desirable adjunct, as it would permit the use of peat less carefully prepared and containing more water, and the economy would be greater than in any other way of firing.

Peat Powder.—Next to the producer gas, peat powder is the most attractive form of fuel for firing boiler furnaces, for operating kilns of various sorts, and for the metallurgical operations mentioned. This form of peat fuel has not yet been so generally used in Europe as has producer gas, and not as much has been demonstrated commercially in regard to its value. The most recent reports are very favorable and indicate that peat powder can be cheaply produced and is as good fuel for boiler firing when properly prepared and fired as the same weight of good English coal.

Domestic Uses.—The steadiest and, in the aggregate, the greatest demand for peat fuel may be expected to come from small consumers who want a clean, easily handled, and cheap fuel that gives out a steady heat and yet responds quickly to changes of draft when burned in ordinary heating and cooking stoves. Doubtless in this way, as a supplementary and auxiliary fuel, much of the peat that is gathered for fuel will be used.

Peat Coke.—Peat coke is the most efficient solid fuel derived from peat, but its high cost of preparation will doubtless limit its use even more than that of charcoal is now limited. Its value for all uses to which charcoal is now put should find it a ready and satisfactory market after it has once become known to the industries that require such a product.

PEAT AS A RAW MATERIAL FOR PRODUCTS OTHER THAN FUEL.

For many years the peat beds of Europe have been studied to see if the great quantities of partly decomposed, fibrous plant remains that are found in them, and that can be recovered seemingly at low cost, could not be made into articles of commercial value which would replace those now made from more expensive materials.

It must be borne in mind, however, that most kinds of vegetable raw materials are scarce in the countries of northern Europe where this experimental work has been carried on, and command a much higher price there than can be obtained for similar materials in the United States. There is, therefore, a much greater incentive to find substitutes or adulterants there than in this country, where potentially valuable vegetable substances are extravagantly used or allowed to go to waste. Material better than peat for some of the uses that have been proposed for it in Europe is at the present time wasted lavishly in some parts of the United States where peat is found, or in nearby territory.

Chemical Products.—In discussing the manufacture of peat coke and peat gas in preceding sections, the possibility of obtaining a variety of chemical substances of commercial value was brought out. These materials are actually made on a commercial scale in Europe as by-products of peat-coke plants by condensing and redistilling the heavier gaseous products of distillation. In this country the same compounds are obtained as by-products of making charcoal, and to a rapidly increasing extent some of them are recovered from coal-coking plants and illuminating gas and power gas producers.

The recovery of chemical by-products from the destructive distillation of any fuel requires a carefully planned recovery plant, so designed and arranged that it will handle automatically, at the least possible expense, large volumes of liquids, containing a small percentage of salable material; to do this the greatest possible economy of heat and power must be effected. In addition, the cost of supervision and of skilled labor necessary for such recovery plants is considerably greater than for plants making less complicated products. For these reasons the manufacture of acetic acid and acetates, wood alcohol, formaldehyde, ammonia and its compounds, phenol and creosote compounds, and the products which can be derived from the tarry residues from peat distillation, such as illuminating and heavy oils, paraffin wax and asphaltum, can be profitably undertaken only at large plants, well designed and constructed, sufficiently capitalized, and properly managed.

It is significant that several plants erected in connection with large lumbering operations, for utilizing waste wood, by distilling the lighter compounds mentioned above, have not been successful. The reasons for failure have not been that the products were not in demand at good prices, or that there was any inherent difficulty in any of the processes, but that so far as could be learned, the margin of profit was so small, and the expenses of maintenance so great, that the owners preferred to close the plants and waste the materials which they attempted to save or to convert them to other uses.

There seems to be no question whatever, from the reports published, that all of the chemical compounds which have been mentioned can be profitably made from peat, and that there is a market for many of them in large and increasing quantities, but it seems assured, also, that they can be made with profit only in large and costly plants in which charcoal or coke is obtained from the peat as the principal product, or in those in which large quantities of peat are gasified to generate fuel or power gas.

Alcohol.—Within a few years there has been a revival of interest in a process by which ethyl or "grain" alcohol can be obtained from peat. It has long been known that cellulose could be broken down into sugar by proper chemical treatment, and that the sugar could be converted into alcohol by fermentation induced by yeasts, as in the ordinary production of alcohol from cereals and fruits.

The revival of this process was reported from Denmark, Sweden, and France, where experimental factories were established to test a newly discovered yeast, and from them came the reports that alcohol could be made from the coarser and less decomposed types of peat, at a total cost of between 45 and 50 cents per gallon. Later accounts state that the Danish plant has closed indefinitely without commercial operation.

The process of making alcohol from peat, therefore, is still in an experimental stage. It may never reach the point where it will be used in this country, as in many communities apples and other fruits rich in sugar and sugary waste of various kinds are allowed to decay in large quantities when, for a smaller cost than peat can be used, they might be converted into alcohol for fuel uses.

Ammonium Compounds.—The process of Frank and Caro[1] for obtaining ammonium sulphate as a by-product incidental to the

[1]See also section on by-product gas producers, Bull. 16 Bureau of Mines, pp. 158-159.

development of producer gas from peat has been mentioned in the discussion of producer gas. From 70 to 85 per cent. of the combined nitrogen of the peat, often amounting to more than 2 per cent. of its dry weight, is recovered by this process.

The peat, which may contain from 40 to 60 per cent. of water, is superheated with an excess of steam in the drying zone of a Mond gas producer, decomposing the nitrogenous compounds and converting part or all of them into ammonia. The steam and gases from the producer are conducted through pipes to washers and ammonia-fixing apparatus, where the free ammonia in the gas is brought into intimate contact with sulphuric acid and converted into ammonium sulphate. The dilute solution is periodically drawn off at the bottom and concentrated by evaporation. It may be filtered and purified by crystallization. This process is reported by Caro[1] to be in use at Sodingen, Germany, and at the large peat electric power station of the Hanover Colonization and Moor Improvement Co., at Schweger Moor, in northwestern Germany.

Ammonium sulphate has a rapidly increasing demand because of its high value as a constituent of the best types of fertilizers, and the cost of equipping a plant of sufficient size to profitably manufacture it from peat on a commercial scale is the chief factor to be considered by those contemplating its production.

By the Woltereck process, which is the discovery of Dr. H. Woltereck, of London, England, the discoverer claims to get a part of the nitrogen for the ammonia directly from the air and only a part from the peat. This claim is backed by the reports of a long series of carefully conducted laboratory and large scale experiments, which have been worked out seemingly with great scientific accuracy and attention to detail. The assertion is made that when wet peat is burned in a specially constructed furnace at a temperature barely sufficient to keep the fire alive, some of the nitrogen of the moist air, constantly forced into the combustion zone of the furnace, forms ammonia by uniting with the hydrogen of the organic matter that is being decomposed. The gas from this wet combustion contains tar, tar water, and other distillates from the peat, besides the ammonia. In a large plant now in process of development in Ireland these gases are conveyed from the furnace to a scrubber that removes the tars without condensing the water, as this water would contain a part of the ammonia. From the tar scrubber the hot gases are sent to an alkali tower, where a hot solution of soda or milk of lime removes the acetic acid, as sodium or calcium acetates. The acid may be recovered by later treatment. The gas next passes to similar towers in which it is met by a fine spray of hot, dilute sulphuric acid, which combines with the ammonia to form ammonium sulphate, the chief object of the process. The acid is used

[1]Caro, N., Chem. Zeit. 35: 56: 506-7, 1911.

until nearly or quite neutralized, when the solution of ammonium sulphate is drawn off to crystallizing vats, concentrated by evaporation, and purified by crystallization.

The process gives no fuel gas, as the temperature at which the peat is burned, 750° to 950° F. (400° to 500° C.) is too low to permit the formation of carbon monoxide or hydrogen. The process is consequently one purely of chemical manufacture, based on the formation of ammonia from the nitrogen of the air and of the peat itself, by the slow combustion of wet peat, the statement being made that peat with 75 per cent. of water can be successfully used in this way.

The plant for manufacturing ammonium sulphate by this process must be of a large size to be profitable, because, as in other chemical industries, the cost of production increases disproportionately as the output is decreased. The inventor of the process estimates a minimum production of 5 tons of ammonium sulphate from 100 tons of theoretically dry peat. The plant now being erected in Ireland, it is estimated, will manufacture at least 5,000 tons of ammonium sulphate per year when in operation, besides acetic acid, paraffin, and other chemical products of secondary importance. The cost of constructing the plant now being built will be approximately 100,000£ ($500,000). If, however, the discovery is as stated, this investment is justified by the needs of the agricultural interests of the world, which are making constantly increasing demands for more sources of combined nitrogen suitable for fertilizing purposes.

Nitrates.—Peat has also been proposed as a means for the intensive production of nitrates on the following principle pointed out by Muntz and Laine. A culture bed of peat, watered with a dilute (0.75 per cent.) solution of ammonium sulphate, then inoculated with nitrifying organisms and kept at a temperature of 38° C., yields, after a time, nitrates to the amount of 0.82 per cent. By repeating the application of ammonium sulphate five times, the quantity of nitrates developed amounts to more than 4 per cent. This may be washed from the bed and purified. The peat may then be used for fuel or for distillation. Whether this process is adapted to the commercial production of nitrates on a large scale is not yet demonstrated, but in view of the rare occurrence and limited supplies of these salts, so vitally important in agriculture, it presents possibilities of great importance if the facts relative to nitrogen fixation are as stated. The fact that all of the world's supply of grain alcohol is obtained by the action of microörganisms on sugar solutions, often of considerable dilution, points strongly to the conclusion that no great difficulty would be met in applying to commercial operations the principle stated by the authors quoted. If, however, the only change effected is to convert to a nitrate the nitrogen compound supplied to the peat from ammonia, the value of the process is questionable.

Dyestuffs. — The well known brown color of water flowing from peat deposits may be greatly increased in strength by adding alkaline substances to wet peat, as they dissolve some of the organic acid compounds. The resulting brown compounds can be again precipitated as insoluble substances that are said to give a permanent brown color and that could probably be utilized as dyes. The color can also be obtained in the form of a brown powder by adding an excess of acid to the alkaline solution first obtained and filtering.

Materials for Tanning.—Tanning materials have been obtained in Europe from peat. It has long been known that peat, especially those types in which woody plants were abundant, contains tannic acid, tannin, and related substances in considerable quantity. The process of preparing the tanning material is thus described by Ryan:[1]

> The powdered peat is treated with nitric acid in cemented cisterns until a small part of the product ceases to give brown fumes when boiled with an excess of nitric acid. The mash is then diluted with water and heated by a current of steam for several hours. A solution of stannous chloride is added, and the boiling is prolonged until the dark color of the solution has changed to a light brown, when the liquid is decanted from the precipitate and can be used directly for tanning hides.

Other chemical products that can be obtained are discussed in the sections of this bulletin relating to peat coke.

Paper. — Peat containing much fibrous matter has been manufactured into paper, chiefly in a single factory established for the purpose at Capac, Mich. The machinery was invented in Europe, but has been brought to perfection in this plant, which was reported by the owners to be the only one in the world at the time it was erected.

The product thus far manufactured is cardboard of a dark color but good quality, suitable for making boxes and for similar purposes. The raw material can be bleached, but seemingly the coloring matter of the peat is so durable as to render bleaching too expensive for commercial purposes.

In 1910 a small plant for making coarse brown paper from peat mixed with wood pulp and other paper stock was erected near Garrett, Ind. The product finds ready sale.

The chief objections to using peat as paper stock can be briefly stated as follows: There is much waste material, including water and mineral matter, which must be handled before it can be eliminated; peat is usually uneven in structure and texture; the fibrous matter is small in quantity, was originally poor in texture, and has been weakened by decay. Hence the peat fiber often has to be enriched with wood pulp or other paper stock to produce even poor grades of paper. The fiber is also difficult to bleach, so that only coarse brown papers and cardboard can be manufactured. Most types of peat contain very

[1]Ryan, H., Reports upon the Irish peat industries, p. 415.

little fiber and are too thoroughly decayed for use as paper stock, and it is probable that less than 10 per cent of the peat deposits of the United States are suitable for paper making.

Probably the only kind of bog that may be considered suitable for this purpose is one which has been built up from the bottom by successive layers of grasslike plants to a considerable depth and over a large area. Poorly decomposed moss peat, by the addition of a small percentage of paper stock, might be used for making some grades of paper. The bogs with a 3 or 4 foot stratum of mossy, fibrous, or woody peat at the top and structureless material below would be of small value for paper making, nor would those of small area be available, since the cost of equipping a paper mill is large.

Paper and pasteboard made from mixtures of varying quantities of peat fiber and wood pulp have been produced from time to time in several countries of Europe, where a considerable number of processes have been patented, but generally the manufacture has not been continued beyond the experimental stages because of the high costs of reducing the peat fiber to a condition suitable for use.

Woven Fabrics. — The stronger fibers from the more fibrous kinds of peat may be separated and cleansed from the surrounding material, and after treatment which renders them pliable they may be woven into fabrics. The most successful experimental use for this kind of cloth has been as blankets for horses and other live stock.

It has been reported recently from Europe, also, that the fiber obtained from the remains of the sedges that frequently grow in moss bogs is collected by hand as the peat is run through disintegrating machinery, and is used for adulterating silk threads and fabrics, for which purpose it is in growing demand. After the material is sorted, or in the case of purer fibrous peat without such sorting, the entire mass is beaten up with water, after which the fibers are gathered by means of forks moved by an endless chain. The fibers are removed by the conveyor to large vats, in which they are washed with water, again collected, partly dried, placed in hot acid solution, washed, and allowed to ferment, and then dried. The dust which still adheres to the fibers is next removed by proper screening, and the cleansed fibers are prepared for spinning. The cost of this material is about the same as that of hemp and flax, about twice that of jute, and only a little less than that of cotton, even in Germany, where it is produced.

Artificial Wood. — A material called "Heloxyl," closely resembling heavy paper, was made by compressing fibrous types of peat and hardening the resulting material by special treatment into sheets, blocks, and other forms for structural purposes. The material was light, compact, waterproof, and nonconductive of sound, vibrations, and heat, and could be made fireproof by the introduction of mineral matter; it was also readily glued, nailed, and painted, and because of these properties, as well as its strength and lightness, made good finishing material.

Artificial wood, made by mixing fibrous peat with certain mineral cements and compressing it, has also been made in a small way in Germany. The material can be molded into any desired form, is incombustible or slow burning, does not absorb water, and is so tough and hard that it is said to make good and durable paving blocks and flooring, as well as a desirable substitute for wood in most of its ordinary uses.

Mattresses and Sanitary Appliances. — Moss peat and material which has been selected and freed from sticks and other coarse matter, or the roughly cleaned fibers derived from peat, may be made into mattresses and dressing for wounds.

The absorbent, deodorizing, and antiseptic properties of peat make it good material for these uses. The mattresses are said to be especially valuable for hospital use, since they are light in weight, resilient, soft, inodorous, and very cheap, so that they can be renewed at small cost.

The material used for dressing wounds needs more thorough preparation than that intended for mattresses, as it must be freed from all dirt and woody matter, and, on the whole, there is doubt whether it possesses sufficient superiority to substances now in general use for the same purpose to warrant trying to introduce it. In the form of fine powder it has been used with excellent results in dressing cuts, burns, and other wounds, and its many good features for such use merit investigation by American surgeons.

Moss Litter and Mull.—A much more general use for the more fibrous kinds of peat in Europe is for bedding for stock, and in the form of powder or mull for various packing, absorbent, and deodorizing uses.

Moss or peat litter is hardly to be classed as a manufactured product, since the common processes of manufacture consist chiefly of cutting the peat into large blocks, spreading them on the bog to dry, gathering the peat blocks in a partly dried condition, and tearing these up by the use of simple machinery. The shredded material is passed through rotary screens to separate the finer material, or mull, then dried artificially and packed in bales. This material is capable of absorbing much larger amounts of moisture in proportion to its weight than any other substance in general use for stock bedding. It is a good deodorizer, and almost entirely prevents the decomposition of the nitrogenous and other organic substances for a considerable time. In addition, it is reported to be springy and durable and to keep the feet of the animals which stand on it in perfectly healthy condition.

At the present time a considerable quantity of this sort of litter is imported from Holland and other countries of northern and western

Europe; in 1909 it amounted to something over 9,000 tons. It was made for several years past at a single plant at Garrett, Ind., but this is no longer in operation. About 8,000 tons of this material are imported annually from Holland.

Many of the peat bogs of the northern United States are favorably situated for manufacturing this material, and the peat is admirably adapted for this use, judging from the imported product that has been examined by the writer. This substance is chiefly composed of poorly decomposed sphagnum moss and other herbaceous plants, and is of a light-brown color when dry.

Packing Material. — Peat prepared in about the same way as the moss litter is largely used in Europe for packing fragile and perishable articles, and there seems no reason why it can not be used for the same purpose in this country, where much more expensive substances are now employed. This use should be extended to include the packing of eggs, fish, meats, and fruits for cold storage, as is done in Europe. The antiseptic power of the peat adds to its value for this purpose. An exhaustive series of carefully planned experiments with the proposed packing material in various forms and with varying water content under American conditions is needed before any considerable investment for producing it on a commercial scale in the United States can be recommended. Peat moss (*Sphagnum*) is gathered and baled in considerable quantities in New Jersey, and to a less extent in Ohio and in New York, for packing and for florists' use.

Fertilizer Filler.—The most extensive and successful use of peat as the base of a commercial product sold in large quantities on the open market in this country is as "filler" in artificial or chemical fertilizers. This filler should not be regarded, however, as a harmful adulterant, but rather as a diluent, or in some cases as a necessary constituent of the mixture into which it is introduced, since it improves the whole, both mechanically and chemically; for the same purpose manufacturers use powdered graphite, coal dust, cinders and ashes, sand, etc. The use of peat powder as filler also permits the use of many kinds of waste animal matter, rich in valuable nitrogenous compounds, which could not be used otherwise because they absorb water from the air and cake, or give off offensive odors, and soon decay, their valuable nitrogenous content being dissipated as gases (pp. 380–384)

The processes of preparing peat filler are even simpler than those for peat litter. The peat is dug or plowed up and allowed to drain and become as nearly air-dry as may be, after which it is dried artificially, often in a rotary drier, to a low moisture content, ground into a powder, and shipped in bags or in bulk. The grinding may be done before the artificial drying.

The only factory of this kind operated in Ohio is the large plant of the Farmers' Farm Company near Plymouth.

Conclusions.—Peat is available for any of the uses cited in this discussion and some others which have not been considered here, but it can hardly be classed as a satisfactory raw material for making any of the more complicated products under the usual conditions existing in Ohio, where other and established substances are already to be had in any desired quantity and at satisfactory prices. Moreover, these products are obtained from peat only by large investment of capital and, in most cases, can not be manufactured before the plant has passed through a long experimental period, which must be properly provided for by a considerable fund established for the purpose.

The simpler products, peat litter, mull, mattresses, packing material and peat fertilizer filler have a much greater chance of being quickly made profitable, because some of them are already on the market, and present uses for which the peat is especially adapted. Moreover, the processes of preparation are simple and the cost of equipment for their manufacture with tried machinery is so low that moderate expenditure will fully equip a plant to produce them, and it is unnecessary to provide for a long experimental development.

It is apparent therefore that the more fibrous kinds of peat, where they are found in Ohio, may be put to a number of profitable uses, besides making them into fuel, while the black, plastic types which are of frequent occurrence, have other possibilities, although they are not adapted to the same uses for which the first may be recommended.

PART II

History and Development of Ohio Peat Deposits

CHAPTER V

ORIGIN OF PEAT DEPOSITS AND THEIR VEGETATION

The necessity of correlating the vegetation of a region with topographic forms and the various changes through which they pass has been shown by many writers. The great biological significance of environmental changes needs no further emphasis than the statement that biological surveys and causal and genetic studies, whether of plant associations or of animal societies, must take into account correlations if they are to become more than mere collections, lists or notes with occasional miscellaneous information. In the search for data one must not lose the perspective and overlook the influences which are fluctuating and dynamic, and those which have worked through long periods of time and seem static. It is relatively easy to classify any region on the basis of habitat factors such as water, light, soil. Outdoor observers are familiar today with the well defined process of base leveling and the related differences of topographic forms in slope, exposure, drainage, soil structure, water content, humus, etc.,[1] and the related changes in vegetation types. A study of physiographic changes in an area is, however, of fundamental importance in the interpretation not only of present changes in plant associations but also in tracing their remote past and the immediate future of plant habitats and vegetation succession. The Ohio flora is not a product of present conditions alone; the past is involved with the present; old life relations are inextricably woven with the new life conditions. The sources of the Ohio flora, the paths and directions of migration, the relationship to neighboring states, the limits of distribution in this State or in time and the general division of the vegetation into plant regions, can only be determined by physiographic changes and other environmental conditions past and present. A peat deposit, in particular, illustrates the preservation of the past in the present and the successive stages of development that constitute its history.

[1]Chamberlin, T. C. and Salisbury, R. D., Geology, Vol. I, 1906, chapters II-VI. Woodworth, J. B., American Geologist, Vol. XIV, 1894, p. 231.

But geographic and physiographic ecology is merely the foundation to an inquiry into the physiological causes of the similarities and differences existing among vegetation units. Greater prominence needs to be placed upon plant response to understand the factors with which plants react individually, in replacement and in distributional relationships as social organisms. This study of life relations between plants and their habitat, both as a phase of organic response and of development and movement of plant associations is known today as the science of ecology. If the essential aim is to comprise all of the main questions as to methods, procedure and conditions in evolutionary movements, more must be attempted than has been done thus far.

It has now become possible to carry prolonged and exact physiological investigations into the field, the "home" of plant societies. Experiment alone can supply an accurate knowledge of the habitat and congenital reactions of plants, and of the interrelations and conditions of their life. Ecological problems must in the future be approached and conducted on such a basis. The movement, which received its greatest impetus from the classical work of Schimper,[1] has now sufficiently stimulated the character of research to suggest the need of synthetic studies. The work of correlation, which the author of "Pflanzengeographie auf physiologischer Grundlage" so comprehensively conducted, should now be applied in more detail to problems of field ecology. An exhaustive research upon a physiological basis is at present not possible. The principal factors are too numerous and variable, and call for coöperative research. However, one dominant factor impresses itself in any field work—the available water content for plants in the substratum. The physiological and bacteriological experiments of the writer have shown that Schimper's observations on "physiologically dry places" aid in the correlation between structure and behavior of plants, and the soil conditions which they encounter. Chapters VIII to XI show in more detail how changes in the factors controlling that phase of the environment may produce natural successions in the vegetation cover.

Discussions on the history and development of Ohio peat deposits and the types of vegetation frequenting peat areas, render necessary the recognition of the geologic and physiographic factors originally determining the distribution of vegetation. It has now been realized that geologic study tends to a fuller understanding of the historical development of the vegetation of an area. But equally important is the concept of progressive and retrogressive changes in the relations as illustrated by Crampton.[2] Retrogressions and accidents of various

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[1]Schimper, A. F. W., Pflanzengeographie auf physiologischer Grundlage. Jena, 1898.

[2]Crampton, C. B., The vegetation of Caithness considered in relation to the geology. Edinburg, 1911. See also Cowles, H. C., Bot. Gaz. Vol. 51, 1911, pp. 161-183.

kinds must be taken into account. The part played by contingency relative to the obstacles encountered in a given place and at a given moment is often great. The dissociation of the usual tendency to succession into divergent, relatively discordant lines, gives rise to secondary successions and to a different course of progression. The whole bog series travels several divergent lines, and either another, longer road, or a shorter one of which it cannot even be said that there is a series or an outcome such as pointed out below (p. 261). The detached parts reunite themselves to what is nearest to them. There are numerous such cases in the State, but at present it is enough that the main law of succession is indicated. In the following pages the attempt is made at defining some of the possible historical relationships of the vegetation to the geology and the physiography of the State. Nothing more is intended than that the interpretation, tentative though it may be, should serve to stimulate further investigation.

There are many special aspects which constitute subdivisions of genetic and dynamic ecology, but they are only phases in the treatment of the subject. In giving, therefore, a description of the geology and the physiographic features of Ohio in relation to the beginning and the succession of vegetation in local lakes and peat deposits, only such of the present group of habitat features have been selected as are of most importance in the distribution of the Ohio bog vegetation.

GENERAL CHARACTERISTICS OF OHIO.

Ohio lies between 38° 27′ and 41° 57′ north latitude, and 80° 34′ and 84° 49′ west longitude. Its maximum length from north to south is 210 miles, and its greatest width from east to west is 220 miles. The area is 41,240 square miles[1] and is divided into 88 counties.

Geology.—A short discussion of the geology of the State has been given in Chapter VII. Briefly speaking, the bedrock of the western half consists of limestones with a subordinate quantity of shales which belong to the Ordovician, Silurian, Devonian and Carboniferous systems. The eastern half of the State, on the other hand, has a rock floor of shales, sandstones, conglomerates and a subordinate quantity of limestone which belong to the Devonian and Carboniferous systems (Fig. 14). These points are well shown on the Geological Map of Ohio (1900).

Soils.—The soils of Ohio were derived in large part from the bedrock and to a much smaller extent from territory north of Lake Erie. When the great glacier first advanced into Ohio from the highland east of Hudson Bay it doubtless found a heavy layer of soil and subsoil covering the surface everywhere except on very steep slopes. This

[1]A recent determination by Prof. C. E. Sherman of the Ohio State Universitv

material was formed by the decomposition of the bedrock and naturally varied from place to place. Where the bedrock was limestone, it was overlaid with a limestone soil; and where it was sandstone, it was covered with a sandstone soil, and so on. The thickness of this material varied much, but was usually greatest in valleys and least on steep slopes.

The glacier mixed the soil and subsoil which it found with materials derived from the erosion of the underlying bedrock. To this it added material which it transported from the north, to a small extent from beyond Lake Erie. It follows, therefore, that the soil of the glaciated areas is dependent primarily on the underlying bedrock and to a subordinate extent on the material which the glacier supplied from the north. Glacial soils are not all of equal fertility, even where the bedrock is the same, for the foreign material added may vary in composition and texture from place to place.

Southeastern Ohio was not overrun by the glacier, and hence the soils are more dependent for their character on the bedrock. As may be guessed, they are usually less fertile and vary somewhat from place to place as do the rocks which reach the surface.

No soil map of the State has yet been prepared, and all that can be done here is to point out a few of the salient features. Naturally the soils may be divided into two great classes, (1) the drift and (2) the driftless.

1. The drift soils cover about three-fourths of Ohio or all that part that was overrun by the great glaciers. Along the shore of Lake Erie, and extending as far south as the old beach of the glacial lake of the same name, the soils form a loam. This area is narrow from Norwalk east but widens rapidly to the west, the southern edge passing through or near Fostoria, Findlay, Lima and Van Wert. Occasionally morainic ridges of clay are found on it, and elsewhere patches of sands, but as a rule it is very fertile and suited to gardening as well as to general farming.

The western half of Ohio, or to be more exact, the part south of the lake belt just referred to, and west of a line drawn from Sandusky south to Circleville and thence southwest to Ripley, Brown County, has a limestone floor which has yielded a soil of unusual excellence. The northern portion of this area is often clayey with poor surface drainage, which has been remedied by extensive ditching. The southern half contains more sand and gravel, is usually rolling and hence has better surface drainage. It, too, occasionally bears morainic ridges of clay which are less fertile.

Eastward from this great area and south of the lake belt is a strip of drift soil that varies greatly in width, and is underlaid chiefly with shales and sandstones. Its surface may be very flat and swampy, gently rolling or even hilly, and its soil varies greatly from county to county or even within smaller limits. The best soil is excellent, while the poorest is sometimes worth little except for grazing.

Several valleys within the glaciated part of our State deserve special mention because of their size and great fertility. Notable among these are the Miami below Dayton, the Scioto below Columbus, the Mad River and the Maumee.

2. The unglaciated part of Ohio comprises the southeastern quarter and is underlaid with shales, sandstones, and to a lesser extent, limestones. The topography is nearly everywhere hilly, small tracts being too rough for cultivation. It is diversified by deep valleys, some of which, as the Muskingum and Tuscarawas, are wide and contain valuable tracts of high quality soil. Drainage, of course, over this great area is excellent. The soil varies with the bedrock and hence changes from place to place. That derived from limestone is usually notably more fertile, but on steep hillsides it is of little value because of the topography. The other kinds of bedrock have yielded a thin sandy soil.

Topography.—The topography of Ohio varies much (Fig. 12). The southeastern quarter is nearly everywhere hilly, and the remaining three quarters usually undulating or flat. The highest point is in Logan County and reaches an elevation of 1,540 feet above sea level.

At the base of the Pennsylvanian or Coal Measures system and near the top of the Mississippian or Lower Carboniferous the rocks consist in part of conglomerates which resist weathering. Below these lie shales and thin sandstones which weather rapidly; consequently the former rocks meet the latter with steep slopes or escarpments which are usually conspicuous from the Pennsylvania line southwest to the Ohio River. Eastward from this line the topography is nearly everywhere hilly and forms the western part of the Allegheny plateau, while to the west it is almost always rolling or flat. Were it not for the work of streams these two topographic areas would meet in a curving line without sharp reëntrants or projections. The streams, however, have in many places cut through the conglomerates and now flow over the less resisting shales, so that the line of junction is extremely tortuous. Often small areas of the former variety of rocks have been detached by streams and now stand as islands on the softer shales. Examination of the geological map of the State (Fig. 14) will make this clear.

The watershed between Lake Erie and the Ohio River is a very important though much less conspicuous topographic feature. In the western part of the State it is situated in Darke County, running northeast from there in a tortuous course, and lying only about 30 miles from the lake in Summit and Trumbull counties. Small lakes, marshes and peat bogs frequently occupy depressions on or near the summit of this divide, which indicate that it is not a sharp narrow ridge but rather a broad, low dome with an uneven surface.

Northward from the divide the slopes are gentle in western Ohio but steep in the northeastern part. Hence the descent of the streams is slow in one area and rapid in another. The Cuyahoga River with its gorge-like character is an excellent illustration of the latter class; and the St. Marys with its sluggish current and shallow, narrow, drift-cut valley, of the former. South from the divide the streams descend with varying but usually gentle slopes to the Ohio River. The valleys vary greatly in age, some being preglacial and others postglacial, and hence may be wide or narrow, deep or shallow. Occasionally they vary much in these respects within short distances, good examples being found along the Little Miami River, Paint Creek, Rush Creek and the Licking River.

The topography along the Ohio River in our State is everywhere rough. Tributary streams, large and small, have dissected the land, producing high narrow ridges with deep steep-sided valleys. In the southeastern part this form of topography extends many miles north and west from the Ohio, while in the southwestern part the reverse is usually true, the glaciers having there smoothed off the surface and the streams not having had time since the ice withdrew to carve it into ridge and valley.

The topography of the unglaciated part consists essentially of ridges and valleys whose relative heights and depths increase toward the principal streams; naturally they are greatest near the Ohio River. Occasionally, however, the surface is rolling, as in parts of Muskingum, Belmont and Gallia counties, and the western half of Washington, but such tracts comprise a very small part of the total area. Drainage in this part of our State is excellent and hence bogs or marshes are wanting.

The glaciated part of Ohio presents considerable variation in topography, but in the main it is flat or gently rolling. What the relief of this great area was before the ice advanced is not known in detail, but part of it at least was rolling or even hilly. In general the glacier eroded tops of hills and dropped the material in nearby valleys, thus leaving a new land surface smoother than the old. In places, however, the hills seem to have been but little eroded, though in such places the valleys have usually been filled and the surface inequalities thus reduced. This phase is best shown near the margin of the drift sheet.

The surface of northwestern Ohio forms a plain with usually but little relief. In places it is difficult to decide in what direction the drainage flows unless a stream is consulted. Variation from this monotony is provided by low morainic ridges, the beaches of glacial Lake Erie, shallow valleys and to a much greater extent by the hills near Bellefontaine, which, as already stated, form the highest land in Ohio.

The surface of southwestern Ohio is more diversified, owing to the rougher topography which the glacier encountered and to the longer time that the streams have been working on the drift. A third reason should be added—the greater size of the morainic ridges which occasionally have a width of five miles or even more and a height of over 100 feet above the surrounding plain. Good examples of such are in Champaign and Clark counties. The more level tracts of this quarter of the State occur in Madison, Pickaway, Fayette and Darke counties.

Climate.—The general climatic conditions of Ohio,—temperature, rainfall and amount of sunshine—are fairly stable and depart little from the normal.[1] The change in weather conditions is rather rapid but the main factors which determine growth (p.307) rarely vary beyond favorable limits.

The average annual temperature is 50.7° F. The warmest month is July with the highest recorded temperature of 113°; the coldest month is February with the lowest extreme of −39°. The extreme range is 152°. The growing season has an average number of days varying between 134 and 195. The length of days between sunrise and sunset varies around 9.2 hours (for January) and 15.2 hours (for July).

The annual precipitation for the State is 39.89 inches. The greatest rainfall for one month is 17.33 inches in June; the average number of rainy days for the year is 122. The snowfall averages less than 20 inches in the extreme southern portion of Ohio and over 60 inches in northeastern counties. The average annual relative humidity is 78 per cent. at 7 a. m. and 69 per cent. at 7 p. m. The prevailing winds are from the southwest over most of the State, and vary slightly with the season. The average hourly wind movement is nearly 9 miles and is greatest near Lake Erie.

Vegetation Regions.—The State may be divided into four plant-geographic regions, which in their climatic conditions follow closely the divisions given in the four special section reports, issued recently by the United States Weather Service (Fig. 12). The regions are characterized by certain peculiar topographic features on the basis of which they they have been named as follows:[2] 1. The Lake region; 2. The Western Plain or Calcareous region; 3. The Scioto Valley region; 4. The Appalachian region.

The following discussion includes only a brief and very concise account of the general environmental relations and their vegetation features, since the strictures imposed upon the writer by the nature of this bulletin do not permit an adequate presentation of such an important subject.

1. THE LAKE REGION.

Section 69 of the climatological service of the Weather Bureau, includes the territory drained by the Maumee, Sandusky, Black and Cuyahoga rivers which flow into Lake Erie. The area is entirely

[1]Smith, W. J., The climate of Ohio. Ohio Agricultural Experiment Station, Bull. 235, 1912.

[2]Selby, A. D., and Duval, J. W. T., Jour. Horticultural Soc., Vol. XXXV, 1899, p. 38.

within the glaciated district and forms a somewhat monotonous plain with rolling elevations over which the streams flow by circuitous routes. They are not over 50 miles in length. The rate of descent is relatively great near the divide, averaging from about 10 to 15 feet per mile.

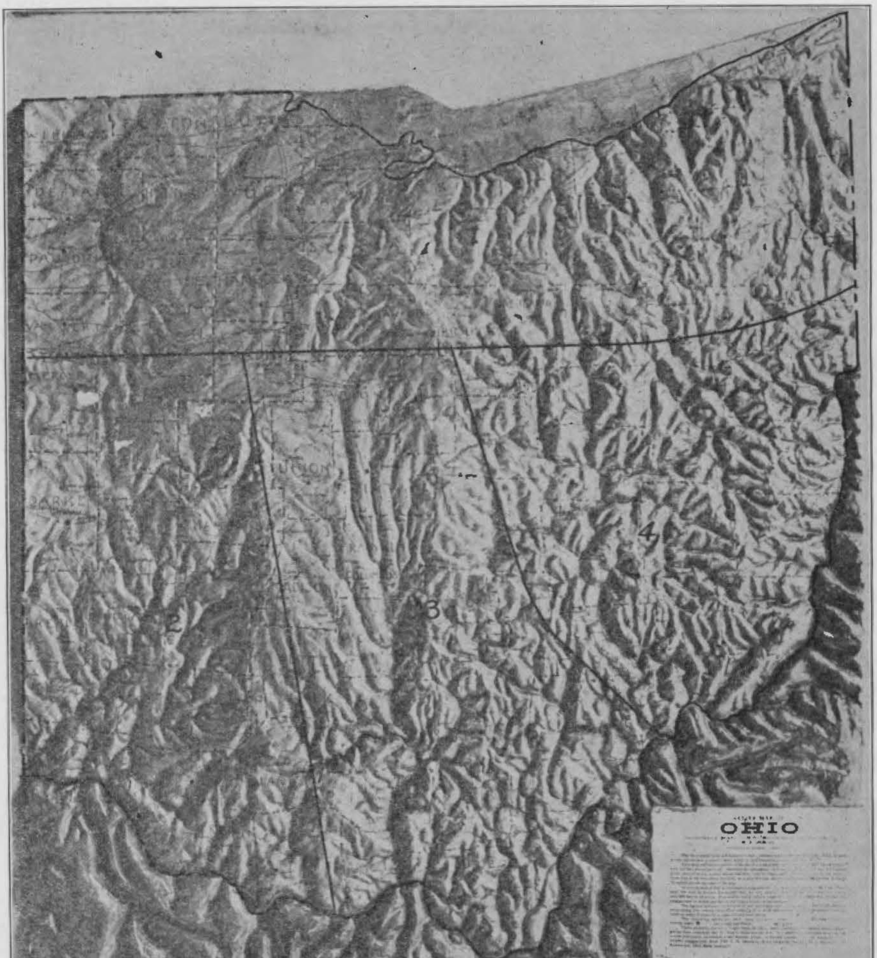

Fig. 12.—Relief map of Ohio with climatic and vegetation regions. (1) The Lake region; (2) the Western Morainic Plain or Calcareous region; (3) the Scioto Valley region; (4) the Appalachian region.

Near the lake the rivers are sluggish and wind in and out through low, flat, often marshy land.

To the north and west the area is more rolling. In the western central portion is the "Black Swamp," which is bounded by a series of sand, clay and gravel ridges from 10 to 20 feet in height. They are old beach lines and mark the outline of a glacial lake at different periods in its recession.

In the southern portion of the Lake region are numerous depressions in which water stands permanently. They are the poorly drained finger lakes and plains along the great water shed, which have furnished the places for the formation of some of the larger and better grade peat deposits.

The average annual temperature for the Lake region is 49.3° F. The highest annual mean is 51°, the lowest 47°. The highest temperaure recorded is 105° for July; the lowest is −32° for January. The absolute range is 137°. Temperatures below zero occur during the months of December, January, February and March. The earliest date of first killing frost in autumn occurs about the middle of September and the latest date oftener late in May than in early June. The average length of the growing season varies around 168 days.

The average rainfall is 36.5 inches; its distribution is very uniform. The heaviest precipitation is more frequently in September, the least in February. The number of rainy days is on an average 122, with a relative humidity of 74 per cent. The prevailing wind direction is southwest.

The primitive forest consisted of southern deciduous trees and associated species which extended into southern Michigan. Today the greater number are maple and beach, with oaks and hickories[1] growing on the ridge summits, plateaus, and on the outcrops of Niagara limestone. Oak openings are a striking feature; they afford a transition to the invading prairie vegetation. The forests within the "Black Swamp" (see map, p. 27) had the same floristic composition that was found by Schenk[2] in the lower Wabash valley in Illinois, and hence may be considered as the northward extension of the Mississippi bottom hardwood forests. The "Black Swamp" is characterized by an entire absence of conifers; bogs are found rarely. On either side of this area the northern coniferous forest association and bogs are plentiful, with many boreal plants. They are island-like areas, surrounded by deciduous trees and dependent species associated with the hardwood forests of the Appalachian district.[3] Eastern and western floral elements blend at various places and frequently on sandy ridges and ancient dunes. The influence of the lake is seen in the climate, which is greatly ameliorated when compared with that of the inland sections. Grapes, strawberries, peaches and apples are in little danger from spring frosts. Moseley[4] finds a notable difference in number of species existing between

[1]Jennings, O. E., A Botanical Survey of Presque Isle, Erie County, Pa. Annals of the Carnegie Museum, Vol. V, 1909, pp. 289-417.

[2]Schenk, J., Catalogue of the Flora of the Wabash Valley. Geological Survey of Illinois, 1875, pp. 504-579.

[3]Harshberger, J. W., Phytogeographic Survey of North America, 1911, pp. 474-496.

[4]Moseley, E. S., Climatic influence of Lake Erie on vegetation. American Naturalist, Vol. XXXI, 1897, pp. 60-63.

the west end and the east end of Lake Erie. He states that 233 species occur along the southwestern shore which are not found elsewhere.

THE WESTERN PLAIN OR CALCAREOUS REGION.

This region embraces the southwestern part of the State and includes the watershed separating the Maumee River from several streams flowing into the Ohio. It is section 70 of the climatological service of the Weather Bureau. The area includes the Grand Reservoir in Mercer County, having an elevation of 875 feet, and the Lewiston reservoir in Logan County, 968 feet above sea level. There are greater extremes in elevation in this section than in any other portion of the State. The territory, all of which has been glaciated, consists of comparatively level areas of usually heavy limestone soil marked with rolling moraines. No abrupt changes are found except where the streams have cut their valleys in the soft drift. The rivers flow with an average fall of 4 feet per mile. In the southern part the surface is very hilly and diversified by the erosive action of the Ohio River and its tributaries. The great valley of the Ohio is several hundred feet below the general level of the State.

The average annual temperature of section 70 is 52.5° F. and the range between extremes is relatively great. The highest temperature reached is 109° in July, and the lowest is —34° in February. The absolute range is 143°. A temperature above 99° has never been recorded at Urbana, near which a cedar bog, typical of northernmost regions, is found. The temperature often falls below freezing every month except in June, July and August. The average length of the growing season is 164 days, beginning late in May, the date of latest killing frosts, and ending in the latter part of September, the earliest killing frosts of autumn.

The annual precipitation averages slightly less than 39 inches. June is the wettest month and October the driest. The average number of rainy days in the year is 112; the average annual relative humidity is 71 per cent. Prevailing winds are from the southwest with an average hourly movement of 8 miles.

The prairie plants and those of southwestern range are chiefly limited to this region. They are represented only by forms which readily invade a variety of habitats and mingle with the grasses of shallow peat prairies and oak openings, and with deciduous forests. Two types of coniferous forests are found, represented by almost pure stands of tamarack and of white cedar. Bogs and peat prairies are characterized by patches of shrubby cinquefoil (*Potentilla fruticosa*). The region is in part floristically related to the lower Wabash Valley in Illinois, but has not been studied actively from the standpoint of plant geography.

3. THE SCIOTO VALLEY REGION.

This is section 71 of the climatological service of the Weather Bureau and includes the Scioto watershed with that of the Hocking River and other smaller streams flowing into the Ohio. The northern part of this division is a more or less level plain about one thousand feet above the level of the sea. The surface of the southern part has been worn and chiseled by erosive agencies into thousands of ridges and cone-shaped hills, deep ravines, and sandrock bluffs with steep fronts. "All that is wanting," says one observer, "to complete the horizontal plain of rock which originally covered the area, has been worn away by eroding streams." The valleys of Southern Ohio were eroded chiefly by streams in the form they now have through long periods which antedated that of glaciation. Generally they were eroded below the level of the present beds, for the streams now flow upon alluvial and drift material. Many of the original channels have been reduced in dimensions by the silt and drift of the succeeding ice age.

The valleys of the Hocking River and of the Scioto and its tributaries as far down as Chillicothe, are shallow; numerous marshes are found along the Scioto, especially in Hardin County. The remainder of the course of these streams is through deep valleys, bordered by hills 400 feet or more in height.

The average annual temperature for section 71 is 53.5° F. The warmest month is July with the highest recorded temperature of 113°. The lowest temperature occurs at most stations in February with the greatest minimum of —32°. The temperature is frequently below freezing every month, except June, July and August. There is an absolute range of 145°; it is greater than that of any section in the State. The growing season begins between the 10th and 30th of May, the latest date of killing frosts in the spring, and ends about the middle of September, the earliest date of the first killing frost in the fall.

The annual precipitation averages about 38 inches and is quite uniform in distribution. June and July are the wettest months; the least rainfall is in October. The average annual number of rainy days is 106. The mean annual relative humidity is about 72 per cent. The prevailing winds are from the southwest.

The plants of this area are geographically an extension of the southern deciduous or hardwood forests and their dependent associates, which once covered almost entirely the great Ohio basin.[1] The early settlers found this a vast forest of most remarkable variety in species. The absence of conifers, except along the steep bluffs of narrow valleys and in special and usually restricted localities, is very notice-

[1]Harshberger, J. W., Phytogeographic Survey of North America, 1911, pp. 409-460.

Green, W. J., and Secrest, E., Forest conditions in Ohio. Ohio Agri. Experiment Station, Bull. 204, 1909.

able. The forests extending back from the river bluffs present a talus and rock cliff flora which shows distinctly Appalachian elements, with "boreal plants" and many peculiarities common to the extension of the coniferous and deciduous forests of this mountain range. The presence of so many plants peculiar to the Appalachian mountains makes it certain that the isolated forms are but relicts of types of plant groups which once were more continuous and widespread, and which have been preserved in a few localities where the environmental conditions were especially favorable. This important principle of plant geography is in evidence in many localities of this section.

On the northern plain peat deposits are common; on the southern hilly portion barrens are frequent, covered with an open forest of crippled oaks and trees of stunted growth.

4. THE APPALACHIAN REGION.

Section 72 includes the larger part of the Muskingum watershed. Only a small area of the northern part of this section, possibly eight per cent., is glaciated. The topography varies from the rolling glaciated country to the hills along the Ohio River, where most of the minor streams run in deep valleys cut in the bedrock of the carboniferous plateau. Floods are frequent because of the hilly character of the country, and water basins along streams, oxbow lakes and bayous are so filled with the various forms of sediments that accumulating plant remains have little if any economic value.

The annual mean temperature is 52° F. The warmest month is June, recording 105°, and the coldest is February with —39°. The absolute range is 144°. The growing season is between April 18th and September 28th, the dates of latest and earliest killing frosts.

The annual precipitation is very nearly the same over the entire district and is nearly 40 inches. The largest monthly fall usually occurs in June and July, and the smallest in October. The number of rainy days is fairly constant, being about nine per month. The mean relative humidity is about 73 per cent. The prevailing wind is generally from the southwest.

The vegetation of this section is typical of the western and northern extension of the Appalachian mountain range. Broad-leafed species of both the Alleghenian and Piedmont plateaus in early days covered and dominated the crests and summits of the hills and all the intervening country; the lowland flora was confined, as now, to narrow borders of sedimentary origin along the streams. In all probability the flora of the precipitous ravines and deep gorges will show relict endemism, such as has been described for Hocking and other counties in the Scioto Valley region. Nothing has been published on the plant geography relations of this region, and the writer has no observations of his own to offer on the characteristic floral components of it. Peat deposits have not been found.

HISTORIC FACTORS.

The Ice Age and Its Effects.—The physiographic differences and the present distribution of plant and animal life exhibited in Ohio are an effect of certain past conditions, primarily glacial and post-glacial. In attempting to determine the affinities and interrelations of the present lake and bog vegetation, it is therefore necessary to take into account the past conditions, that is, the physical history of the State, its past climate and topography, and their effect upon the subsequent distribution of vegetation.

In another chapter (VII) it was pointed out that the great geologic series above the Carboniferous, comprising the Mesozoic and Tertiary time divisions, have no record within the State. It seems that, after the deposition of the last coal-bearing rocks, Ohio remained permanently above sea level. A long period of time intervened, during which the types of rock and of life peculiar to this geologic series came gradually into existence. The evidences of the intermediate life must be sought, however, in other states. In Ohio it existed and disappeared with the soils of that time.

The changes of level during the Tertiary period involved at its close an emergence of the great interior of the continent so that the land areas reached nearly the outlines which they have at present. The general slope of the surface must have been very different from that at present. The Ohio River did not exist at that time as a separate stream. Its present channel was occupied by a series of disconnected water courses, varying in size from small ravines to large rivers.[1] Many of the streams in West Virginia and in eastern Kentucky flowed northward across the state of Ohio, using the drainage channels now occupied by streams flowing in the opposite direction. Presumably they entered river channels now the site of the great lakes and the Wabash River.

The great feature of the Tertiary vegetation was the presence of flowering plants.[2] Beech, sycamore, tupelo, oak, tulip tree, sweet gum, walnut, magnolia and others were represented by numerous species. A forest of great denseness existed, extending far north into the arctic regions. The coniferous vegetation was of the same general type all over the continent. The flora of Europe and America had much similarity.[3] A temperate climate, very much warmer than now and somewhat subtropic, extended to the northern boundary of the United States, as is shown by the fossil plants about the arctic regions. An arctic bog flora must have existed north of this great forest in the polar lands.

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[1]Tight, W. G., Professional Paper No. 13, U. S. Geol. Survey.

[2]Penhallow, D. P., Notes on tertiary plants. Trans. Roy. Soc. Canada, Vol. X, 1904, pp. 56-76.

[3]Engler, A., Versuch einer Entwicklungsgeschichte der Pflanzenwelt seit der Tertiärzeit, Vol. I, 1879-82, pp. 3-5.

Knowlton, F. H., A Catalogue of Cretaceous and Tertiary Plants of North America. U. S. Geol. Survey, Bull. 152, 1898.

At the close of the Pleistocene repeated glaciations were initiated. Several theories, characterized by the particular agency involved in the hypothesis, have been offered respecting the cause and the checking of the glacial period.[1] But whatever the causes assigned, whether changes in elevations of the land, changes in oceanic circulation due to extension of great masses of land, changes in the atmospheric "permanent lows" and related storm tracks brought about by a reduction in the carbon dioxide content in the atmosphere, or changes in astronomical relations either as variations in the eccentricity of the earth's orbit or in the obliquity of the ecliptic with a wandering of the earth's pole—the basal conception is that a combination of conditions became dominant which tended to accelerate, intensify and extend glaciation beyond its present border. The great continental glacier, as is well known, has not yet completely disappeared even today; a part of North America and Greenland is still buried under ice.

Ohio was then in large part covered by an ice sheet which moved from the northeast at a sharp angle to the Ohio divide referred to in preceding paragraphs. The glacier must have been prodigiously thick, for in the course of its movement it passed over and planed off the tops of the highest hills and, elsewhere, even mountains of considerable size. It ground up the underlying rocks and carried the derived material both within and under the ice. Upon the surfaces of many rock exposures it formed numerous parallel scratches and grooves by the scraping rock fragments embedded in the moving ice. Boulders often show similar scratches. The glacier brought down rock fragments and boulders to the northern part of Ohio, the material of which is peculiar only to areas of Canada. It buried the State under ice, possibly several thousand feet in thickness, thus making the western and northern portion a glacial desert. The border or glacial boundary is indicated in Fig. 14 and on the map recently published by the Geological Survey of Ohio.

Among the first effects of the southward progression of the ice margin was the ponding and holding back of the water of northward flowing streams. Valleys were flooded; their basins and all of the lowland became lakes and the streams were forced to seek new outlets. Thus the drainage system, which probably found its outlet into the channels now occupied by the great lakes, became in large part reversed. The water from the great region of melting ice still further contributed to the general inundated condition of the low-lying land in Ohio. New water courses were carved and many narrows or gorges now mark the places where they broke through the minor watersheds that restricted the flow to the Ohio basin. Thus the Ohio River began its existence with the advent of the ice age.

Not one but several such glacial periods and invasions of ice have left

[1]Chamberlin, T. C., and Salisbury, R. D., Geology, Vol. III, p. 424, 1906.

their marks upon Ohio since the beginning of the Pleistocene. The drift border or glacial boundary is, according to Leverett,[1] a combination of four out of six invasions now recognized in America. It is formed in part by a sheet of drift that appears to be the Illinoian but possibly is still older; and in part by the earlier and later Wisconsin drift. The Iowan or fourth invasion is not found exposed in this region.

They were separated by long intervals with milder climatic conditions, such perhaps as now prevail in latitudes four to five degrees farther south. Various proofs have been found to support this view, among which are the character of the drift material, parts of plants which now flourish only in the Mississippi basin,[2] and the accumulations of peat and humus-bearing soils between the different sheets of drift. No important plant accumulations are known between the two Wisconsin stages.

In Ohio blackened clay and loam are found buried beneath more recent drift beds of unusual thickness, often at a depth of a hundred feet. The buried soil of several southwestern counties contains leaves, branches and trunks of trees, and constitutes, therefore, an ancient surface of the land, a surface which was converted into a soil, covered with forests and tenanted by animal life. An occurrence of fossil peat in the glacial drift has been described on page 103; others have been noted by Orton; and it is very probable that there are still several deposits of this sort in the State.[3] But it is by no means certain that the cases cited belong to the Wisconsin stages. Pleistocene forests and peats are not widespread in Ohio; and since they are in many cases too deeply buried they have little or no commercial value. They are, however, of the greatest botanical interest, for they are confirmatory of the views advanced in regard to inter-continental migration of plants and warm temperate interglacial conditions. Further investigations on the nature of Pleistocene vegetation are much desired.

The Distribution of the Ohio Vegetation During the Last Glacial Period.—It is evident that great climatic changes accompanied the advance of the ice sheet. Conditions must have been more or less arctic in their character, long winters succeeding short summers with persistent clouds, fogs and severe winds and storms. With its advance the ice frequently removed the soil and cut deeply into the unweathered rock, developing broad, smooth bottomed, rock basins. Not only was the preëxisting topography modified, but the ice destroyed the plant and animal life in its course and forced upon what survived a general migration southward. Large parts of the great Tertiary forest were broken down and destroyed by the storms of the approaching wintry climate,

[1]Leverett, F., Glacial Formations and Drainage Features of the Erie and Ohio Basins. U. S. Geol. Surv. Mon. 41, 1902.

[2]Coleman, A. P., Interglacial fossils from the Don Valley, Toronto. Am. Geol., Vol. XII, 1894, pp. 86-95.

Coleman, A. P., and Penhallow, D. T., Canadian Pleistocene flora and fauna. Rept. Com. Brit. Assoc., 1900, pp. 328-339.

[3]Newberry, J. S., The forest bed. Geol. Surv. Ohio, Vol. II, 1874, pp. 30-33.

and by the ponding which resulted from the reversal or flooding of drainage lines. Their remains were ground to pieces by the slowly moving ice sheet. The soil which the semitropic species had covered afforded new areas for the growth of arctic and bog plants which spread in advance of the ice invasion. Only such species of the forest as oaks, ash, and several conifers survived that could grow under the influence of the increasing cold. The individual plants suffered extinction, but the species in their southward extension migrated by growth and the transportation and establishment (ecesis) of their seeds. The variety of life became greatly reduced. Plant associations, originally separate, were overtaken and in their habitats became mixed with the invading vegetation. Thus the migration of northern plants, and their crowding upon those living in the temperate zones continued and brought an intermingling of associations and societies of plants, in some habitats ranging from the arctic to the most southern climate.[1] As a result of the action of the ice sheet the original Tertiary forest became more completely separated into two great types, the Atlantic and the Pacific. The arid tracts of the west resisted the expansion of the incoming vegetation with its many forest trees, its shrubs, herbs, and ground cover, and the associated animal life. For the greater part, therefore, vegetation kept within the far western and the eastern humid regions.

In front of the ice there spread a vegetation of the tundra type, which moved southward with the advance of the glacier and the denuded area fronting it, until it came to the position shown by the drift border or glacial boundary. In dominance of species, breadth of zone and range of distribution, the tundra type of vegetation was probably controlled less by character of soil and soil preferences than by the great range of temperature, both daily and annual, the length of growing season and the exposure to active erosion and floods.

These same conditions characterized the area just beyond the ice margin in which the conifers were dominant. As in Alaska and Switzerland at the present time,[2] conifer forests probably existed along the margin of glaciers. The higher elevations beyond the reach of active glacial erosion, and the areas of high relief along the southern Appalachians were favorable to pine, arbor vitae, hemlock and spruce[3] with the dependent undergrowth; while in ravines, in undrained depressions, and on the borders of the heavily loaded, cold, silty streams existed the bog vegetation in a variety of habitats similar to those of their life relations in northern Michigan today.

[1]Cowles, H. C., A remarkable colony of northern plants along the Appalachicola River (Florida), and its significance (Abstract). Rept. 8th Inter. Geogr. Congr. 1905, p. 599.

[2]Russell, I. C., Glaciers of North America, 1901.

[3]Gray, A., Forest geography and archaeology. Am. Jour. Sci., Vol. III, 1878, pp. 16-85.

Hooker, J. B., The distribution of North American flora. Am. Naturalist, Vol. XIII, 1879, pp. 155-170.

The extreme area of ice front in Ohio, the cold silty waters of the glacial streams, the great amount of erosion connected with the glacial drainage and the accompanying deposition of silt make it doubtful whether the Tertiary broad-leaved deciduous forests then native to the Ohio basin competed with the conifer-oak forests, and could have persisted near the ice front or north of the Ohio River. South and beyond this stream, the basin along the relatively warmer streams flowing from the south was undoubtedly occupied by chestnuts, walnuts, hickories, magnolias, maples, elms and others. The conviction is unavoidable, that the ice sheet affected the distributional relationships at a relatively great distance from the ice front, that the limits of the warm temperate types and even the tropical belts were considerably shifted[1] and compressed, and that the plants were forced to spread south along the Appalachian highland and the coastal plain. Judging from the extent of local peat deposits and from the present northern limits of some broad-leafed species, it seems probable that they did not persist at that time north of the river. A great many bog plants occur today on the coastal plain as far south as Florida[2]; the species are not always the same, but they are systematically related and closely similar in ecological structure. Their presence so far south today and the colony of northern mesophytic plants noted by Cowles (l. c.) can be explained only on historic and topographic grounds. In the southern Alleghenian area the native trees were met and overlapped by the bog plants, birch, hemlock, maple and associated undergrowth; they mingled with the relicts of a more ancient vegetation, the magnolias, tulip tree (*Liriodendron sp.*), bald cypress (*Taxodium*), sweet gum (*Liquidambar*), tupelo (*Nyssa*), and the vegetation of the tropics.

Three distinct centers of population became thus established in the eastern half of North America, composed of plants and animals from all possible directions. Along and just beyond the ice margin and on the higher parts of the Appalachian, the climate and soil favored a tundra vegetation and conifer forests with an extensive undergrowth of dependent associates and bog plants. In the southeast and upon the slopes of the southern Allegheny mountains the genial climate and abundant rainfall favored the preservation of deciduous forests in greatest development and variety. In the southwest the aridity of the soil and the climate determined the establishment of the prairie and desert types of vegetation, with sage brush, nut pines and junipers.

The vegetation was in constant response to stimuli. "Every advance and recession of the ice sheet affected it and enforced renewed oscillatory migration. It seems scarcely possible that plant and animal life, still in the process of northward dispersal, has succeeded in balanc-

[1]Chamberlin, T. C., and Salisbury, R. D., Geology, 1906, Vol. III, pp. 483-493.
[2]Harper, R. M., A preliminary report on the Florida peat deposits. Florida Geol. Surv., 3rd. Ann. Rept., 1910, pp. 196-376.

ing the state of stress encountered, and in readjusting itself to the complicated relations involved in changing habitats." The selective action of the evironment and of antecedent habitats must have increased in some plants the ancestral fixity of function as well as of structure, while in others ecological and taxonomic characteristics must have become more plastic, and response extremely erratic or else in a direction of the structural impress and physiognomy of the habitat. Undoubtedly extreme stimuli of different factors produced alterations in germ plasm and hence new types of diverging as well as similar growth forms. Many plants reacted to various conditions in the environment, with results that would have the profoundest influence in the distribution and the range of the species. The occurrence of a number of plants and animals which are not to be found elsewhere indicates that it was the time and the region of new species, as well as of preservation and of greatest development. A vegetation much richer not only in types but in plasticity and in range of reactions developed by these changes.

As the winter conditions of the glacial period slowly changed to a milder climate, the ice sheet began to diminish and to recede northward. A heavy mantle of clay, sand and bowlders was deposited, some beneath the ice and some at its edge. The deposition of the drift again altered the topography. A complex series of pondings of glacial water took place between the ice border and the higher land fronting it, giving rise to a succession of temporary, constantly changing lakes and ponds with shifting outlets. Large rivers, cutting deep gorges and valleys through sand, gravel and rock, emerged from the melting ice front into the Ohio and the Mississippi basins.

When the receding ice sheet had reached beyond the northern slope of the Ohio divide the water from the melting glacier formed great inland lakes which for centuries covered the northern area. The glacial Lake Maumee is the highest of those formed in this manner; glacial Lake Whittlesey, the close successor, stood about thirty feet lower; glacial Lake Warren had its borders forty to seventy-five feet below the level of Lake Whittlesey. To all of these lakes the Ohio divide was for a long time a barrier. The series of lake ridges, which run in parallel lines over the surface lying between the present lake shore and the summit of the present watershed, show the indisputable record, somewhat obliterated by time, but easily traced and mapped.

While the northern slope was being covered more and more deeply with lacustrine sediments filling and obliterating the older drainage channels, the water overflowing the ridge gradually cut a gap and discharged itself through the Maumee Valley and that of the Wabash to the Mississippi River. Several other gaps were cut through the great barrier. The Cuyahoga water gap which connects the valleys of Black River and the Cuyahoga with that of the Tuscarawas, and possibly the St. Mary's gap which connects the valleys of the Maumee and Miami, are further examples. These great rivers, "which never had a name and no man ever saw," cut broad and deep valleys through sand, gravel and rock, and were the main drainage channels until the water of the glacial lakes contracted to successively lower levels and was drained in other directions.

The surface of the drift deposit in the western and central counties of the State is marked by numerous lake plains, with weak shore lines and a level floor of fine lake clay, in many instances overlaid by marl and peat. The shore lines are the positive evidence of wave action. These and many smaller glacial lakes resulted from valley glaciers associated with the withdrawal of the ice sheet. As the glacier withdrew it occasionally halted, and built large moraines which prevented the waters finding an outlet. There were formed finger lakes and broad shallow water basins, which in the majority of instances did not persist to the present but became filled with vegetable matter and are now marshes and peat bogs. The most striking instances of such basins, still occupied in part with water, are found in a belt on or near the crest of the great watershed, the Ohio divide. This series of water basins, partly bogs and swamps, characterizes the high lands of the watershed not only in the State, but also in its prolongation into Indiana and Michigan on the west and north, and in Pennsylvania and New York on the east. Almost all of the large lakes and peat deposits in Ohio, as for example Cranberry Prairie in Mercer County, the Loramie reservoir in Shelby County, the Scioto and Hog Creek marshes in Hardin County, the Cranberry marshes in Crawford County, the New Haven marsh in Huron County, Savannah Lake in Ashland County, the Lodi marsh and various lakes in Medina County, the Copley bog and the Turkey Foot lakes in Summit County, the Tamarack bogs in Portage and Mahoning counties, and the Pymatuning swamp in Ashtabula County, are members of this chain of water basins (see map, p. 27).

The Postglacial Migration of Vegetation.—Among the first to occupy the barren soils left by the retreating ice were low forms of the tundra,—stunted willows, alders and birches, with various saxifrages, gentians, mosses and lichens as an undergrowth or alternating as grassy meadows. As plant associations continuous in distribution, they expanded and spread to the north in early postglacial times over soils of better drainage, stability and low water level. Within the United States the arctic vegetation is restricted today to the area above the timber line of the far north and on the summits of high mountains. The few arctic forms, which occur locally in cold ravines and in circumscribed areas of hilly counties, are relicts of this former widespread glacial flora that followed up ravine slopes as the warmer climate advanced. Most of them have disappeared unrecorded.

The late development of northwestern and eastern outlets to the postglacial waters retarded the northern dispersal of many land species.

The conditions favored for a long time the extension of aquatic vegetation only, and the development of marginal associations. The more elevated, drier portions afforded restricted areas in which the occasional seeds brought by wind and birds established themselves, while in the undrained and poorly drained depressions the establishment of the bog plants took place. As in the case of the tundra vegetation, physiographic conditions rather than mineral soil preferences determined their habitat. Slowly they worked themselves up the valleys along the dendritic tributaries in diverging directions nearer to the divide. The tundra vegetation was closely followed by them and perished wherever the vegetation of the sub-arctic transition zone became firmly entrenched. The long duration of the conditions immediately following glacial times, the massive beach ridges, bars, cut-off ponds and innumerable lakes furnished a variety of habitats for these plants, much more extensive than that at present; they were favorable to a rapid dispersion and repopulation. The genetically related associations were not isolated from one another by any considerable space, but occupied the region more continuously than found today. They were gradually reduced in extent through natural causes.

The arctic vegetation aspect did not remain fixed but moved, and increased or decreased in extent depending upon physiographic and climatic changes. Constantly the tone of the landscape changed. The lines of movement northward radiated in all directions. From the banks of the great local streams and lakes, from the more temperate regions, and from the southern centers of dispersal, the returning vegetation moved in definite waves of migration and in successional relations. First came the herbaceous plants whose range is today the widest; then, closely following these, the shrubs and later the trees, which were more limited respectively in extent of dispersal. Their invasion and succession was determined to a large degree in so far as water requirement permitted growth and further distribution parallel with the migration of favorable climatic conditions. Dissemination was further aided by the amount of humus and the character of its bacterial life, by wind, birds and other agencies.

As the beach lines expanded toward the lake with the falling water level and as the land continued to increase in area, the plants and animals followed that belong to a type of coniferous forest associations now present in northeastern North America. They overflowed to the north into Canada and northwest to the Rocky mountains, crowding upon bog meadows and bog heaths, breaking them up into isolated "boreal" islands and surrounding them with extensive forests of evergreens. The "lake region," representing the area covered by the ancient glacial lakes, was still covered by water. Upon the great divide the basins, which were then arms of the glacial lake, supported a bog vegetation and began to deposit peat long before the lowering of the water level consequent to the cutting down of the eastern outlets. These were surrounded and trapped by the evergreen trees. But with the lowering of the water of the lake the bog areas became separated and, though still persisting, are now surrounded by a vegetation type related to drained land. The relation of these two varieties of vegetation is, therefore, in the main one to be considered on historic grounds. From evidence afforded by the time it has taken to cut the gorge at Niagara Falls, geologists believe at least 10,000 years have since elapsed. The bog deposits on the divide can not therefore be older than 10,000 years, but those near Columbus must be much older. In Ohio the time of the migration of bog plants and conifers was prior to the long period of drainage that intervened between the shore lines of Lake Whittlesey and the present lake. The absence of tamarack bogs and conifer forests in the "Black Swamp," in the region from Wayne and Medina counties westward to Williams and Defiance, can be accounted for only in this manner and not because of climatic or underlying geological differences.[1] On the other hand the notable differences in the vegetation between drained and undrained water basins and in swamps can not be accounted for wholly in this manner.[2] Here favorable soil processes and available water requirement favor the marsh and drained swamp plants; they become practically the only competitors for these situations.

The rate of migration is not to be estimated in terms of a time element in which sporadic individual plants migrate a required distance. Plants move in groups, as societies and associations. The time normally required for the migration of conifer forests and their dependent associates against antagonistic drainage, rising slopes, lakes, marshes and other barrier-like features is, therefore, considerably longer than that occupied by the spreading of individual trees. On their approach to the great glacial lake the conifers divided into an eastern and western section. They united again in the region north of Lake Huron and Lake Superior. In many localities in Ohio where conifer and bog vegetation formerly existed they have entirely disappeared. Drainage, decomposition of peat and humus, fire and the settlement of the State have aided in their destruction. They still occur isolated all over the northern portions of Ohio within the glaciated region, but in distribution they are now discontinuous.

Soon a third succession of plants, the vegetation of higher types, the mesophytic (broad-leaved) vegetation group, began to encroach actively from the southern centers of population. From the southeast and from the southwest the plants spread northward, with insects, birds and other associated animals. Stream valleys and uplands,

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[1] Selby, A. D., Preliminary list of tamarack bogs in Ohio. Ohio Acad. of Sci., 1901, pp. 75-77.

[2] Transeau, E. N., On the geographic distribution and geological relations of the bog plant societies of North America. Botanical Gazette, Vol. XXXVI, 1903, pp 407-420.

sandy and clay moraines were alike occupied. As the headwater streams began to capture fellow streams and to drain the isolated water basins, the changes shifted and modified the plant successions, and tension lines were produced between the societies of plants in the various habitats. Bog plants and conifers were surrounded and forced to disappear, except in areas where exceptional circumstances afforded them preservation. By imperceptible gradations the vegetation passed into that of the present. The climatic differences of the arid west appreciably restrained the east and west migration that might otherwise have prevailed, for in the interglacial deposits the arboreous vegetation is found considerably farther west than at present.[1]

A special phase of the record are the remains of boreal animals found in the beds of peat and muck of the late Wisconsin drift. The great *Mastodon americanus* and the beaver-like *Casteroides ohioensis*, gigantic elks and other extinct animals were present, dominating the marshes and forests.

Man's presence in glacial times is still an open question. He undoubtedly was forced to migrate southward and to avoid the colder climate; for the earliest historic records and the evidences of his prehistoric activity are most numerous in regions of a semi-tropic character. It is not known just when Ohio became the chief center for the peculiar people who, for want of a better name, are known as the mound builders. Prehistoric human relics do not represent in the opinion of recent writers, "ages" or geologic divisions. The cruder forms of their workmanship are believed to be rejected products; they are abundant as first stages of manufacture in and about the gravel beds, where there was usually much quartz and flint in the convenient form of pebbles and cobblestones. The evidence of cave deposits is negative in Ohio; it has not yielded human relics as in Europe, where the mass of material gathered by geologists and archaeologists is much more satisfactory and supports evidence of man's considerable antiquity.

That the glacial drainage channels, the tributary streams and valleys of the Mississippi, and the water gaps were among the earliest highways for the dispersal of many forms of life is no longer an inference. The gorges and ravines of northern and southern Ohio have a special interest and significance both as related to the system of erosion which has given character to Ohio topography, and as to the remarkable colonies of northern plants left stranded in them. Especially in the gorges and ravines with steep north-facing slopes is to be found an aggregation of plants that is abundant far to the north. Among them are many mesophytic species which dominate in northern forests. They are plants that failed to follow up the last retreat of the ice, and so were cut off from the main arctic or cold temperate vegetation, became completely isolated

[1]Bessey, C. E., The forests and forest trees of Nebraska. Ann. Rept. Neb. State Bd. of Agr., 1888, p. 93.

and later suppressed. They occur now only sporadically in small numbers and are gradually dying out. They are preserved in their southern limits on account of the habitat conditions agreeing most closely with those which prevail farther north. As relicts they are the living record of the former boreal life.

The desirability of studying individual variations and modifications in plants along the highways of dispersal and in relation to the divergence from their environment and center of distribution, does not seem to have fully impressed itself upon the botanists of the State. Plant variations are still too largely expressed in terms of taxonomic differences. Size, dominance of type, degree of variability with departure from a habitat or a localized focus of dispersal, continuity of dispersal and of environment, of variations in form, function and habitat behavior—all these are ecological relationships, the importance of which is certainly of considerable economic as well as scientific value.[1] Little attention has been paid, in the study of the Ohio vegetation, to the geographic aspect of ecology from a dynamic and genetic point of view. The relationships of relicts can only be traced by the fact that the plants belong to an historic order of succession, distinct and earlier from that to which the surrounding associations belong.

[1]Merriam, H. C., Life zones and crop zones of the United States. U. S. Dept. Agr., Biol. Surv., Bull. 10, 1898.

Adams, Chas. C., Southeastern United States as a center of geographic distribution of flora and fauna. Biol. Bull., Vol. III, 1902, pp. 115-131.

CHAPTER VI

FORMATION AND DEVELOPMENT OF OHIO PEAT DEPOSITS

ECOLOGICAL VEGETATION UNITS

The preceding pages have dealt with a brief statement of the origin of Ohio peat deposits and their vegetation; we are now prepared to consider in greater detail the following problems:

(1) What are the vegetation units from which peat is derived and how are peat deposits formed?

(2.) What relation does the vegetation in lakes and on peat deposits, as it occurs in Ohio today, bear to the great migration which this vast aggregate of plants has made since the glacial period?

(3.) What causes are responsible for the successive changes of vegetation in the course of the filling-in of a lake or pond?

Peat is formed wherever plants can grow in profusion, provided that conditions are such as to interfere with the complete disintegration of plant tissue and to favor its accumulation. In Ohio peat accumulates under three topographic conditions; that is, on three types of land surface. But whether the peat deposit occurs in deep depressions filled with water, such as lakes and ponds, or along subsiding border areas of Lake Erie, or on flat land surfaces, as in the case of flood plains and plateaus, a consideration of the formation and accumulation of the material involves factors and conditions affecting plant growth. These remain the same in nearly all cases (p. 307). In method of development, however, the accumulation of peat and the character of the vegetation from which it is derived differ essentially. In the case of lakes and ponds peat is formed by the growth of generations of plants replacing one another at the side and at the top of the basin, while in subsiding areas and upon shallow flat depressions the deposit is built up by vegetation from the bottom of the depression. In structure, texture and properties the peat of either type differs considerably from the others.

There are various ways upon which one might decide for a discussion of the formation of peat deposits and of their vegetation with its primary subdivisions. An enumeration by counties shows the individual differences of bogs, but the details would include too great a repetition of the character common to all. There are the interesting physiographic conditions which have an important bearing in the interpretation of the varieties of peat, and the development of the vegetation from the initial stage through the successive appearance and replacement of different plant associations to the climax vegetation.[1] The vegetation might be considered from the point of view of the gregarious habits of plants to form societies and associations, differing accordingly in vegetation composition, in one or more of the direct habitat factors, and in the manner of encroachment upon the original lake, pond or shallow depression.[2] Or one might group the plants found in bogs and peat-depositing water basins into characteristic dominant growth forms to record the conditions of life, the interrelationship with plant structure and function, the types of peat and of vegetation.[3] In order to understand the developmental process an attempt might be made to discover and correlate by the methods used in experimental physiology, the fundamental principles in the vast field of vegetation, and to determine the influence of soil and climate.[4]

Ecology, whether geographic, floristic or genetic, is still in a very plastic condition and in consequence new points of view may be approached without prejudice. In the process of peat formation the replacement of vegetation units, and the differences in the distributional relationship of plant groups might depend more directly upon historic conditions long past, such as have been enumerated above, or upon available water content of the soil, upon soil processes, and upon special methods found in plants for reacting to the various organic and inorganic constituents of the habitat. The ecological conditions of the habitat should then be quantitatively determined in order to correlate the individual differences in the vegetation zones and the continuity and sequence of successions. How much further the framing of categories or the process of subdivision should be carried rests entirely on differences of opinion and on previous training. Not all of the lakes and peat deposits have their surface vegetation arranged in zones. Many bogs contain a mixed vegetation of aquatic, marsh and even dry land plants. The problem is complicated where the zones are not sharply defined; for though of the same character, they show quite a difference in the series of succeeding vegetation zones, which may be due to differences in the area, depth or age of the water basin, or perhaps to the fact that certain plant societies established themselves in one basin but not in another contiguous to it.

In the statement presented below, the formation and development of Ohio peat deposits and the ecological aspects of the vegetation cover are considered in relation to processes and the causal and limiting

[1]Cowles, H. C., The physiographic ecology of Chicago and vicinity. Botanical Gazette, Vol. XXXI, 1901, pp. 73-108, 145-182.

Crampton, C. B., The vegetation of Caithness considered in relation to the geology. Edinburgh, 1911.

[2]Clements, F. E., Research methods in Ecology. Lincoln, Neb., 1905, pp. 292-306.

[3]Warming, E., Oecology of Plants, Oxford, 1909, pp. 137-148.

[4]Schimper, A. F. W., Pflanzengeographie auf physiologischer Grundlage. Jena, 1898.

conditions in the environment. As a result of investigations carried on in the field and in the laboratory certain correlations have been determined between the different types of vegetation from which peat is derived, and the available water content of the soil occupied by each type. Other factors enter into the correlation, but the data in hand permit the tentative generalization that the relation between the available water content and the respective quantity required by plants is the chief limiting factor. A more detailed account of the methods used by the writer in his studies of the last eight years is given in part III of this volume.

Since the postglacial migration of plants the following major successions of vegetation have led to the establishment of the existing flora on peat depositing lakes, and in shaping the particular associations: (1) Open water succession; (2) marginal succession; (3) shore succession; (4) bog succession; (5) mesophytic succession. There are a number of secondary successions which have been brought about by the destruction (fires, drainage), and removal (cultivation) of the original vegetation. As here listed this sequence of groups indicates the structural and historical relationships. The more genetically related groups and their associations were formerly not isolated from one another by any considerable space; they occupied the region more continuously then than today.

The first three groups are members of a related series in a larger vegetation type—the hydrophytic formation. It culminates in a stable association so far as the free water is concerned. The fourth group is pronouncedly xerophytic in response to physiological drought conditions. The members resemble in many points of form and structure the vegetation of rainless regions and bare rock surfaces—representative types of the xerophytic formation. With the complete filling of the depressions the accumulation of vegetable debris above the water level tends to an increase in the oxygen supply, in available water, and a change in the character of soil organisms and their reactions. The vegetation passes to the mesophytic type of plant formations, which may be regarded as the culminating succession in the progressive series occurring on the peat habitat under present climatic conditions. For the aggregate of plant associations which compose the successional series or sequence on a peat deposit the writer proposes the name "Bog series."

It will be seen that these divisions permit a treatment which may include various systems of classification of peat deposits and of ecological relations. It is an intricate task to discover a guiding principle and to arrange an otherwise confusing diversity into a genetic and dynamic system. But the recognition, that the nature of a peat depositing basin and a bog environment is constantly selective, and that associations of plants succeeding one another are each characterized by a definite physiognomy in response to their dependence upon soil processes and the supply of available water under environmental conditions essentially similar otherwise, renders this classification more significant.

In separating associations only such have been indicated for each succession as were recognized with sufficient clearness to be the controlling vegetation in a habitat comprising elements of stability in the sum of habitat life relations. Only the dominant forms and a few of the more important principal and secondary species can be mentioned.[1] Jaccard's[2] mathematical criterion was used, whenever possible, in delimiting associations. In the literature several papers have been cited from which some idea may be obtained of the seasonal aspect of representative peat depositing basins and their vegetation as well as the more detailed vegetation structure, illustrated by permanent quadrats, by growth form, by vertical layers and by zonation.

SUCCESSION OF VEGETATION IN OHIO LAKES AND PEAT DEPOSITS

What the primary succession was in early postglacial times cannot of course be determined accurately. In addition to the study of the flora, the peat sections wherever practicable, and the remains of such plants as could be readily recognized were carefully studied. From these observations it seems evident that the plants moved progressively as groups very much in the order given below.

In the partly filled lakes and ponds the vegetation from which the peat was formed is, as a rule, the same that is now growing upon or near it. But the plants, which at any given time may be found growing upon the surface of a well filled deposit, have succeeded other plants and in turn will be succeeded by still other invaders spreading over the area. There is, therefore, little correspondence in the completely filled lake or in the heavily forested portions of it, between the vegetation cover and the character of the peat beneath; here the types of plants are not an indication of the origin of the peat or of its quality and depth. Striking instances of the presence of buried shrub associations and forests in the peat have been noted, but a study of the sequence of plant remains in the light of interglacial periods or supporting the view of Lewis[3] has not been attempted.

I. THE OPEN WATER SUCCESSION

1. *Plankton Association.*—In open water the succession of vegetation undoubtedly begins with the plankton association. Bacteria,

[1]For the nomenclature of the divisions, see Schouw, J. F., Grundtraek til en almindelig Plante geographie, 1822, pp. 148-150; also Clements, F. E., Research methods in Ecology, 1905, p. 299.

[2]Jaccard, P., Gesetze der Pflanzenverteilung in der Alpinen Region. Flora, Vol. XC, 1902, pp. 349-377.

[3]Lewis, F. J., Plant remains in the Scottish peat mosses. Trans. Roy. Soc. of Edinburgh, Vol. XLV, 1906-1910.

————, The history of the Scottish peat mosses and their relation to the glacial period. Scottish Geographical Magazine, 1906.

diatoms and single-celled algae are the forms floating in the open water of lakes and of many of the partly filled peat bogs. They are the low and ancient forms which have remained substantially unchanged from a remote geological period in their simple environment characterized by relative uniformity of temperature, light, air and other conditions, and by isolation. They swarm in microscopic myriads, preyed upon by crustaceans and other minute animals. But the reproduction rate is of a uniform average number and holds a steady balance between the prey and foe. The plankton association of Lake Erie and of many inland lakes consists of species in many respects the same as in Europe.[1] In vertical range they are confined largely to the surface of the water. Only the more saprophytic and anaerobic forms sink to the bottom to avoid sunshine and air. There is little question that vertical zonation and seasonal changes in quantity and quality of organisms exist on account of the absorption of light and heat by water, the greater variations of temperature on the surface, the freedom from currents and waves below the surface, and the seasonal circulation or "overturn" in lakes. But these problems await further investigation.

In small pools of stagnant water rich in putrefying organic matter the plankton is quite different in composition, consisting mainly of bacteria and unicellular animals. Infusoria and flagellates, such as *Euglena virides*, predominate, constituting a foul-water plankton association. The saprophytes flourish until putrefaction has proceeded to the stage when the water is devoid of organic matter, and the process of the "self-purification" of the shallow area is complete.

II. THE MARGINAL SUCCESSION

Information of the primary succession along the shallow margin of water basins is less uncertain than our knowledge of the successions in the open water of Ohio lakes and ponds. A careful study of the border vegetation, those places in particular which are least disturbed by man, shows several distinct associations exhibiting zonation and more or less definite layering. But often the vegetation is intermingled to such an extent that structure is scarcely discernible. On account of differences in local conditions and manner of growth or propagation there arises a grouping and localization of species; the mass of vegetation looked at from above appears arranged in dense ecological units, as societies, communities and families. The dominance and the distribution of the respective units is usually associated with the growth form and the mobility of the plants, with depth, clearness and movement of water, with light and heat absorption, and with substratum characteristics. The discussion of the general characters of the water in the soil, and its ecological factors that are of greatest import, will be

[1] Snow, J., The plankton algae of Lake Erie. Bull. No. 22, U. S. Fish Commission, 1902, pp. 371-393.

deferred until the process of peat formation is treated in Part III. (See pp. 348, 373, and tables 6, 29, 30.) The subterranean organs of the different species conflict but little with each other on account of differences in depth from the water surface and in seasonal functioning. The plants invade the area without interference from other rhizome systems, and complement each other largely because of differences in the growth form of their shoots. The growth of plants is on stones and on loose humus. Seasonal aspects, such as are due to flowering and fruiting play a smaller part in the physiognomy of the vegetation, except in the shallower parts of a basin. The plants are present almost throughout the year, and attain their highest point in growth and in numbers about the month of August. At the commencement of winter many produce special thick-walled cells and descend toward the bottom of the water, or hibernate by means of winter buds which are filled with reserve food. In the marginal succession the following associations may be recognized quite clearly.

1. Submerged Associations.—In lakes overlying the limestone area of the western half of Ohio, stonewort (*Chara sp.*) takes a prominent place. The deeper portions of a basin are its characteristic habitat. It often forms veritable mats and is a soil builder of great importance. *Chara* and also crustaceans and mollusks withdraw calcium bicarbonate from the water and deposit it upon their bodies by precipitation as calcium carbonate. Upon the death of the organisms the lime permanently settles upon the floor of the lake or pond. In some lakes and peat deposits the accumulations of fine-grained *Chara* marl or of the comminuted particles of shell marl reach to several feet in thickness. Such deposits are illustrated by areas in which Portland cement works are located, as for instance near Sandusky, where beds of cream-colored *Chara* marl and sheets of calcareous tufa alternating with layers of peat average more than 6 feet in thickness over an area of several square miles. In the Brimfield bog in Portage County, and in many other peat deposits *Chara* seems to have held the entire bottom of these ancient lakes. By its growth the plant filled the depression to a depth of 3 to 4 feet before other plants were able to establish themselves. Where clay or sand forms the substratum the lower layers of marl are usually impregnated with them. Quite often mud was held in suspension in the water at the time the overlying stratum of peat was accumulating. The clay, sand and marl content is only occasionally excessive, making the peat useless for commercial purposes.

Upon areas of shallow water, as at Dallas in Champaign County and at Castalia in Erie County, no vegetation appears except *Chara*. As the soil water becomes less calcareous and more peaty through the addition of organic matter, filling eventually follows the usual course as described below.

Where *Chara* is not present there is but little change from the innermost microphytic region to the belt of submerged plants nearer the margin. The depth of the outer limit of most aquatic plant-growth ranges from 10 to 20 feet, and varies with the clearness and the temperature of the water. At Castalia in Erie County, the "Blue Hole," from which issues a large volume of cold water highly charged with lime, is magnificently carpeted with masses and festoons of algae to a depth of more than 30 feet.

In almost all Ohio lakes the zone of submerged vegetation is rich both in species and individuals. Most of the plants have roots and are attached to the soil, but they do not depend upon the soil for mineral salts. The water-weed (*Elodea=Philotria canadensis*), the water milfoil (*Myriophyllum spicatum*), hornwort (*Ceratophyllum demersum*), bladderwort (*Utricularia vulgaris*), pondweeds (*Potamogeton pectinatus, P. lucens, P. natans*), various mosses (*Hypnum sp.*), and algae constitute the chief peat forming plants in this association. Tape grass (*Vallisneria spiralis*) is less common, but all of the other forms are the same over wide areas. In this respect the similarity throughout the ponds and lakes of Ohio is one of the most striking features. Among these plants the fish chiefly swim or lurk, "scanning the weedy tracts, spending much time in the chase of insect larvae, worms, crustaceans and other animals." The bladderwort, with its tiny traps for the capture of minute insect larvae and crustaceans, is often a serious though unsuspected rival of the fish. It competes with them for food and has the advantage in this competition since it can support itself in case of diminished food resources by the starches and sugars formed in its green leaves. During July and August its flowers determine a pronounced seasonal phase in sheltered places.

Ordinarily hornwort and the *Potamogeton* species comprise the main part of the association in abundance of individuals; next to them in numbers and as principal species are the hornwort and bladderworts; all others are of secondary importance in point of dominance or aggregation.[1] Very frequently the plants are found mingling, but a closer inspection shows that they occur in groups, producing alternation and layering. Lack of space precludes a detailed description of growth forms and of the inter-relationships of roots and shoots. They are similar to those detailed and illustrated by Pieters.[2] There is great variation in the number of species and in the order of their importance; no attempt

[1]Many of the lakes, ponds and small rivers are so affected by the growth of these plants in the shallower waters as to interfere seriously with travel by boat and the catching of fish. In order to clear the marshy bottom of submerged plant growth a weed-cutting apparatus has been invented. (Scientific American, May 20, 1911). The apparatus consists of a boat on which is mounted a frame bearing at one end a set of knives like those of a mower. The frame is so mounted that it may be swung to the bottom of the lake. The knives are operated by means of a hand wheel. The boat is usually propelled by long poles. By operating another hand wheel the frame may be lifted out of the water.

[2]Pieters, A. J., the plants of western Lake Erie, U. S. Fish Comm. Bull., 1901, pp. 57-79. See also Glück, H., Biologische und morphologische Untersuchungen über Wasser und Sumpfgewächse, Vols. I-II, 1905-1906.

is made here to give a complete list. The plants show horizontal distribution and respond to the contour of a basin in about the order in which they appear listed above. They usually exhibit vegetation structure less distinctly than the following association.

The remains of the plants accumulate in large amounts and with almost no decay in quiet basins, often giving rise to a greenish, distinctly laminated peat. Erosion is relatively unimportant and sediments are ordinarily absent from most peat beds. Only with wave action during strong winds, and along gently sloping shores does the debris become ooze-like. By the selective influence of gravity the heaviest and coarsest material settles nearer the margin, while the finest detritus reaches the deeper parts of the lake bottom filling it with a soft, oozy mud.

2. Semi-aquatic or Amphibious Associations.—As the submerged vegetation makes the border of the lake or pond shallower, plants which grow near the shore establish themselves (Plate VI, A). The predominating species are the white and yellow water lilies (*Castalia tuberosa, Nymphaea advena*) and the knotweeds (*Polygonum muhlenbergii, P. hydropiperoides, P. amphibium*). Frequently the mermaid weed (*Proserpinaca palustris*), water parsnip (*Sium cicutaefolium*) and bur-marigold (*Bidens beckii, B. cernua, B. discoidea, B. frondosa*) succeed in establishing themselves in competition with them, but they are either driven to shallower places or grow as secondary species. The plants occupy definite levels below the surface of the water. Usually the creeping stems of the water lilies are below those of the other species, while the rhizomes of the pondweeds and knotweeds lie just above them; mermaid weed, water parsnip, lake cress (*Radicula aquatica* = *Roripa americana*), bur-marigold and others root nearest the surface and become rather abundant in drier situations.

There is no sharp limit between the several associations and those preceding or following them; hence the individual zones contain in great variety species of secondary importance. Most of the plants are perennial and herbaceous, and occur in groups. They are firmly fixed within the substratum by their submerged horizontal rhizomes. As the water level fluctuates, they may exist entirely submerged or only partly so, without apparent relation to the water table, projecting their flowers and often their leaves above the water. All but the water lilies have a plasticity of structure which, seemingly, enables them to respond within a limited degree to situations of a high water level by "water leaves;" especially those of the lake cress vary greatly in form and in structure from the air leaves which arise partly under conditions of a low water level.[1]

The lily zone (*Castalia-Nymphaea* belt) occurs as a belt outside of the pondweeds, in water of a depth varying from one to four feet.

[1]Glück, H., Biologische und morphologische Untersuchungen über Wasser und Sumpfgewächse. Jena, 1905–1911, Vols. I-III.

On its outer part toward the deeper portion of the basin it is always much mixed with the several members of the *Potamogeton* zone. The dominant plants are the yellow water lily (*Nymphaea advena*) and the white water lily (*Castalia tuberosa*). They exhibit occasionally alternation and mingling and have with them as principal species the pickerel weed (*Pontederia cordata*) and arrow arum (*Peltandra virginica*). The individual groups contain as secondary species a mixture of the characteristic plants of the adjoining association mentioned. Only in the outer tension lines (ecotone), that is, along the border between the zone under consideration and the one contiguous to it shoreward, is there an evidence that the more aggressive invading members may occupy a wider area. No attempt will be made here to indicate the variety of arrangement and grouping of principal and secondary species associated with the dominant plants and constituting an ecological plant society. In practically all lakes and ponds visited by the writer the association is represented in concentric zones or in scattered grouping, both showing only minor differences. A typical society, whether of *Nelumbo*, *Pontederia*, *Nymphæa-Peltandra* and so forth, is usually represented prominently by associated knotweeds (*Potamogeton natans*, *P. pectinatus*), hornwort (*Ceratophyllum demersum*), bladderworts (*Utricularia vulgaris*, *U. intermedia*), water weed (*Elodea canadensis*), *Diatoms*, *Desmids* and others.

The white water lily is most often in an abnormal condition. This is brought about by the continual search for its flowers or in making a boat landing. A *Castalia tuberosa* society is more nearly normal in inaccessible ponds; but wherever left undisturbed it soon regains its rank as an important dominating constituent. At Aurora Pond in Portage County the yellow pond lily forms a concentric border 10 to 30 feet in width. In several small shallow ponds the yellow pond lily was found covering the entire surface. At Fowler's Mills in Geauga County both the white and yellow water lilies nearly cover the surface of the pond. Their thick and numerous leaves resting upon the water's surface or rising above it shut out the light to such an extent that the submerged association thrives but poorly.

In a large number of cases the lily zone is bordered shoreward by a wider one of knotweeds. The *Polygonum* species develop particularly well in water less than two feet in depth. The structure of the vegetation associated with them is essentially as follows:—dominant plants (*facies*) are *Polygonum emersum*, *P. hydropiperoides* and occasionally *P. amphibium*. Within these dominant forms appear separately, often in indiscriminate alternation, several principal species, such as the yellow pond lily (*Nymphaea advena*), which characterizes the area and thus gives rise to an aggregation of plants constituting the *Polygonum-Nymphaea* society. The dependent associates and species secondary in numbers, which constitute a more or less independent community, are hornwort

(*Ceratophyllum demersum*), water hemlock (*Cicuta bulbifera*), sticktight (*Bidens cernua, B. discoidea*), and others. In this association the majority of the principal and secondary species are commonly members of the belt of plants previously mentioned, while others are invaders, belonging more properly to the vegetation which is to follow. The numerous seedlings of rose mallow (*Hibiscus moscheutos*), marsh cress (*Roripa = Radicula palustris, R. aquatica*), and others, suggest the probable replacement in the succession.

The variety in zonal arrangement of the semi-aquatic association is often a conspicuous feature. It is due principally to the relative asymmetry and the angle of slope of marginal conditions, depth of water in which the plants can thrive best, dissimilar growth levels of subterranean organs, and the amount of available light and heat. The zones advance more or less concentrically toward a common center. Where an island is present the advance is, of course, from it as a center. Zonation is incomplete or obscured only where the controlling factors change or are unfavorable on account of the interference of man.

3. Floating Association.—Among the members of any semi-aquatic association occur forms of a type of free floating plants higher in the scale of development and differentiation than the type of plants mentioned in the plankton. Some of the constant representatives in open water, relicts of original lakes and ponds, are the duckweeds (*Lemna minor, L. trisulca, Spirodela polyrhiza, Wolffia columbiana*), some liverworts (*Riccia fluitans, Ricciocarpus natans*), masses of algae including *Spirogyra, Zygnema, Cladophora* and others (Plates III, B and V). They are not fixed to any substratum but are free and easily transported by wind and currents. Hence clearly defined societies do not exist in this association. The aggregations consist principally of parent and offspring, and inasmuch as several species contribute loosely to the vegetational structure, they are more correctly termed a community.

At Buckeye Lake the diminutive duckweed (*Wolffiella floridana*) is an important constituent in the small sheltered pools of Cranberry Island; it was brought here undoubtedly through accidental dissemination, by migrating ducks and other water birds.

In lakes exposed to strong winds and to wave action the plants of this association are often thrown on the shore in considerable quantities. This is notably the case at the southeastern shores of the Grand Reservoir in Mercer County and at the Lewiston Reservoir in Logan County. Under these conditions the plants are not an important factor in the formation of peat. But, in protected places along the shore, in miniature bays and lagoons, the floating community exists in great numbers; at times they completely cover the quiet pools and water pockets. The rank growth of this vegetation fills rapidly the areas occupied by them. The normal activity of aerial bacteria soon becomes lessened and the quantities of debris accumulate with little change.

The floating association corresponds in point of vertical zonation to the ground layer of mosses, liverworts and lichens present in any ordinary forest, where the vegetation arranges itself with reference to the available light. In the floating association, light does not seem to constitute the controlling factor. The definiteness and the permanence of the layer must be sought in the extent to which it influences the available water supply in the semi-aquatic and the shore vegetation. With the accumulation of their debris in sheltered and enclosed pools several agencies combine to prevent oxidation, complete decay and the removal of transformation products. The habitat is becoming gradually more and more physiologically unsanitary. As a consequence there is noticeable in the duckweeds a difference in root production as well as in the amount of frond, and later a decrease in the rate of reproduction. This condition indicates a growing season that is shortened by the limitation of the available water supply and by struggles with the reactions exerted upon the habitat by changes in the vegetation.

III. THE SHORE SUCCESSION

The plants that follow the semi-aquatic associations may be called typical forerunners of the land vegetation and of a marsh as well as of peat bogs (Plate V). They crowd into the shallows of a depression and take possession of it by means of strong, much branched, underground stems which form a dense and firm mat. The subterranean organs of the various species show a greater power of changing their direction of growth in response to obstructions than the preceding vegetation units. The plants are more or less competitive, yet mutual relationships, similar to those illustrated by Yapp,[1] still predominate on account of differences in growth form, seasonal functioning and depth from the water surface. The various species thrive and occupy advantageously the different levels by their root systems. In flat basins fibrous roots penetrate deeply into the soil and the mat becomes anchored. As the associations advance to the open water of the deeper portions, the mat becomes a floating shelf, rising and falling with the water level. By a constant accretion of dead tissues the several associations add to the bottom of the basin, shoaling the water shoreward around the sides of the lake or pond. Wind and currents spread the finer debris into the deep portions of the basin and add drift material in varying quantity to the deposit or the silt held in suspension by inflowing streams. Thus conditions arise which enable the more densely populated areas at the margin to advance farther in. The building up of the deposit goes on now more rapidly. The vegetation zones in deep water become narrower as the slope of the peaty accumulation grows steeper, but they broaden

[1]Yapp, R. H., On stratification in the vegetation of a marsh. Ann. of Botany, Vol. XXIII, 1909, pp. 275-319. See also Pieters, A. J., the western Lake Eric, U. S. Fish Comm. Bull., 1901, pp. 57-79.

Pioneer plants building a mat over the open water.

(*Photograph by F. Brown.*)

again as the basin becomes slowly shallow and smaller, or as disturbances in drainage decrease its depth. To repeat then, as the filling-in from the borders of the water basin continues, the debris from plants and, only in a small measure, from animals, gradually raises the deposit along the shore near enough to the surface of the water to enable shallow water plants growing along the border of the lake shore to encroach. The plants are largely perennials and advance as pioneers of the bog or of the land vegetation according to the nature of the water requirement and the determining soil processes. Except the lake bulrushes and closely allied species which may thrive in water five feet deep, the majority of the plants do not grow well in a depth greater than from one to two feet. They form a sponge-like mat by the interwoven rhizomes and roots, and harbor various layers and societies. The association includes all the species which normally raise their foliage above the water surface. A few members are in a sense transitional and can assume an aquatic or terrestrial habit. The plants, mostly monocotyledons, are tall and unbranched with flexible stems and long thin leaves; they attain an average height of five feet, and easily bend to wind and waves. This habit of growth is characteristic even in such members as belong to the dicotyledons. Various societies within sub-zones and layers may be distinguished. They may be pure and dense social growths, or they may consist of societies varying in importance with the dominant species or the seasonal aspect. The following associations may be here outlined.

1. Decodon verticillatus Association.—In the majority of Ohio lakes and ponds with peat deposits, narrow zones of the swamp loosestrife (*Decodon verticillatus*), with occasional cattails (*Typha latifolia, T. angustifolia*), furnish the transition to the bog vegetation (Plate III, B). The slender mature stems of *Decodon* that bend toward and into the open water curve at the tips, form roots, and permit the young plants soon to become moored. In this manner an advance is made outward upon the water. The cattails and various secondary species make their appearance as soon as the stools are built up. Among them are isolated members which represent the abandoned hăbitat of the *Castalia-Nymphaea* association, while the new association is present, sparingly at first but later conspicuously, in the form of several strong societies and communities with invaders of the association that is to follow.

The typical structure of the association is best described as follows: facies or predominating species *Decodon verticillatus*, frequently accompanied by deeper rooting *Typha latifolia, T. angustifolia*, as principal species. Of the secondary species water dock (*Rumex britannica*), cress (*Radicula aquatica* = *Roripa americana*), skullcap (*Scutellaria galericulata*), tickseed sunflower (*Bidens trichosperma*), and later bitter cress (*Cardamine bulbosa*), bittersweet (*Solanum dulcamara*), bristly crowfoot (*Ranunculus pennsylvanicus*), loose-strife (*Lysimachia = Naumburgia thyrsiflora*), and rose mallow (*Hibiscus moscheutos*) with a ground layer of duckweeds, diatoms and blue-green algae constitute the general type. They complement each other largely because of differences in aerial growth form. Water hemlock (*Cicuta bulbifera*), water plantain (*Alisma plantago-aquatica*), bur reed (*Sparganium eurycarpum*) and arrow head (*Sagittaria sp.*) occupy the deeper water, scattered and intercalated to such an extent as no longer to represent a normal stage of the previous successions.

The association forms an attractive but tangled mass through which it is very difficult at times to pass. A great variety of song birds, wading birds, and diving birds, of insects and of other animals make this zone their favorite habitat. There is in the association an early summer aspect determined by the *Rumex britannica* society, which occupies, however, rather restricted areas. A *Hibiscus moscheutos* society is determined during midsummer by the conspicuous flower of the swamp rose-mallow and similarly a *Bidens trichosperma* society with brilliant yellow flowers in early autumn. *Solanum dulcamara* attains in places considerable importance in autumn with its bright yellow berries, but it is never very obvious.

Decodon is entirely absent in a series of small lakes in Ashland and Holmes counties, namely, at Mud Lake, Long Lake and Round Lake. There the sequence of successions is lilies, knotweeds, rose-mallow, followed by arrowwood (*Viburnum dentatum*) and white rod (*V. cassinoides*), poison sumach (*Rhus vernix*) and red maple (*Acer rubrum*). At Ladd's Lake in Defiance County the cattails furnish the transition to a willow-aspen thicket which is followed by a narrow zone of trees, the maple-ash-elm association, on peat about ten feet in thickness.

2. *Carex-Juncus-Scirpus Association.*—In only a few lakes and peat deposits the important forerunners and mat formers are species of sedge (*Carex filiformis, C. interior, C. limosa*) and rush (*Juncus canadensis, J. effusus, J. brachycephalus*). With them are found occasionally *Carex lurida, Juncus acuminatus* and *J. tenuis*. More frequently occur the spike rush (*Eleocharis obtusa*), several grasses (*Panicum sphaerocarpon, P. huachucae, Glyceria fluitans*) and cattail, reed grass and other members of the associations given below. The plants have strong, wiry, but slowly growing, much branched root stocks; once established, however, they form an interwoven, compact mat of turf peat and persist as distinct societies and communities. In flat land surfaces the rhizomes lie at several different soil levels but at considerably smaller depths, often without any relationship. The aerial parts of these plants as they fall to the ground at the end of the growing season become incorporated in the meshwork of fibrous roots and rhizomes. Soil conditions soon become modified, for the dense growth of the plants prevents

excessive evaporation from the ground, the run-off is small and erosion slight, and the delayed surface water is largely absorbed by the spongy network of dead plant tissue. As drainage channels become clogged and the level of the absorbed water rises in the peaty substratum the formation of peat goes on more rapidly. The deposit is continually built up from the bottom by plants best fitted to the existing environment. Complete disintegration of the debris ceases as decay by-products accumulate and reducing action increases. Stability is reached at the height to which water rises from the general level through the spongy mass, and the amount of weathering and carbonization of the softer vegetable tissues in the upper peat layer. Blackened, well decayed layers of peat are frequently encountered in the local peat beds, and often at various levels. They may indicate the effects of prolonged drought due to drainage changes or to atmospheric conditions. Shrubs and trees frequently enter at this stage; and the peat then contains considerable quantities of partly decomposed wood. Only as the rise in water level is sufficiently long and marked, either by increased rainfall or obstructions in drainage, is the work of peat formation continuous or re-established. When the accumulation of peat is not accompanied with a corresponding rise of water level, changes in the vegetation cover follow as indicated on the following pages. The record of these changes is preserved in the deposits, and both the type and the texture of a peat bed indicate the corresponding conditions for peat formation. Deposits of this type can be drained to their bottom.

Peat deposits near Tiffin and the central portion of a bog near Ayersville in Defiance County are covered with sedges. The list of plants includes in addition the following species: *Carex virescens*, *C. canescens*, *C. scoparia*, the wild oat grass (*Danthonia spicata*), five-finger (*Potentilla monspeliensis*), marsh St.John's wort (*Hypericum = Triadenum virginicum*), with patches of sphagnum mosses and the prostrate bramble (*Rubus hispidus*). Around this central portion of the Ayersville bog is a concentric zone of swamp rose (*Rosa carolina*) with meadow sweet (*Spiraea salicifolia*), followed by a zone of high blueberry bushes (*Vaccinium corymbosum*), chokeberry (*Aronia nigra*), etc., with an outer border of willows and poplars (*Salix petiolaris*, *Populus tremuloides*).

Among the plants which share the habitat of the sedges is more specifically the water arum (*Calla palustris*) in the bogs of northwestern Ohio. The bur reed, several arrow heads, the bristly crowfoot and the water plantain with bur-marigold species generally persist as stragglers in the wetter portions of a bog.

In a few inland lakes and especially along the shore of Lake Erie, *Scirpus validus* and *S. americanus* are the forerunners of a pure marsh, followed by cattail and reed grass. The sequence is described with more detail in the *Phragmites communis* association below. Here attention is called to the fact that along the southern shore of Lake Erie the accumulation of peat from these plant groups indicates with certainty the steady sinking of the land surface below the deposits. In the statement regarding the peat deposits of Erie County (pp. 55-58) stumps and roots of trees are associated with an accumulation of peat built up by fresh water plants and especially by the succeeding characteristic reed grass association. The peat beds are now buried below the water level of Lake Erie by later deposits of marl alternating with peat in definite vertical layers. The peat from the aquatic forms is proportionately smaller in quantity and less uniform in texture than that from plants of a drier habitat, showing that the subsidence must have been very slow. Barriers to the northward drainage favored peat accumulation for a period of time that is in proportion to the thickness of the peat bed. The destruction of the barriers and further subsidence supplanted the vegetation cover. Shore material derived from tufa beds and sheets of *Chara* marl spread over all the surface covered by the lake. These periods of subsidence undoubtedly will continue to affect the quantity and quality of peat accumulation.

3. Typha Association.—The cattail and the grass and sedge type of marsh are popularly known as "hay marshes" and "prairies." They are formed by the vigorous growth of these plants over extensive areas formerly covered by shallow water or inundated annually during periods of heavy rainfall. There are numerous tracts, in Mahoning County, for example near Snyder, and in Trumbull County near Orwell and Bloomfield, in which cattails are the most conspicuous plants. They form a very dense vegetation; roots and rhizomes lie at the surface of the peaty substratum and give but little opportunity for the growth of secondary species. Jewel weed (*Impatiens pallida*), burreed (*Sparganium eurycarpum*), arrow head (*Sagittaria sp.*), tearthumb (*Polygonum sagittatum*), milkweed (*Asclepias tuberosa*) and shield fern (*Aspidium = Dryopteris thelypteris*) are representative members of the undergrowth, but scattered to an extent that a final occupation of the habitat is not indicated; they are supplanted eventually by forms intermediate between marsh and shrub, or true bog associations. Species of the greater range in local distribution usually show the greater ability to occupy the ground, to spread laterally with interference in drainage, and to retain possession of an area for a comparatively long period. The *Typha* association is most important in secondary succession, in denuded areas which owe their origin to the activities of man by flooding and fire and which are intended to develop toward a pasture succession.

The headwaters of rivers have their source in many of these marshy sections. The greater part of the area along the river's course has therefore the characteristics of an inundated valley. The vegetation tenanting such areas shows tendencies toward the development of a *pasture association.* This is the case, for example, near Andover in Ashtabula County, about three miles east of the village. It is difficult to characterize the vegetation on account of the large number of weeds and typical marsh plants present. A list of the plants includes the following species: woolgrass (*Scirpus cyperinus*), stonecrop (*Penthorum sedoides*), lady's thumb (*Polygonum persicaria*), water pepper (*P. pennsylvanicum*, *P. hydropiperoides*), sensitive fern (*Onoclea sensibilis*), galingale (*Cyperus strigosus*), yellow dock (*Rumex crispus*), white grass (*Leersia virginica*), cleavers (*Galium trifidum*), water purslane (*Ludvigia = Isnardia palustris*), sticktight (*Bidens laevis*) and marsh speedwell (*Veronica scutellata*).

4. *Calamagrostis canadensis Association.* — This type of shore succession, with *Phragmites communis* on drier parts as a principal component, occupies comparatively large areas in counties along the divide. A *Calamagrostis canadensis* wet meadow succeeds best on a peat substratum which is rarely or never submerged. The *Calamagrostis-Phragmites* association which occupies comparatively large areas of the New Haven marsh in Huron County where it is strongly associated with bog successions, is an example. This meadow association has largely a grass-like aspect and develops a vegetation structure consisting in the earlier stages of the blue joint grass as the dominant species, the reed (*Phragmites communis*), twig rush (*Cladium mariscoides*), shield fern (*Aspidium = Dryopteris thelypteris*), marsh St. John's wort (*Hypericum = Triadenum virginicum*), sensitive fern (*Onoclea sensibilis*) and others. The condition of unstable equilibrium which exists is more favorable for *Calamagrostis* during wet years and more favorable for *Phragmites* during dry ones. The association is followed by stages described later in the bog successions.

5. *Phragmites communis Association.*—Along the shore of Lake Erie and between the bar sections and the mainland there are thousands of acres of pure marsh. In many places the accumulation of vegetable debris, as at Cedar Point[1] and eastward and near Toledo, has been cumulative with the rise of water. The marsh has successfully held the habitat for a long period. The part of the marsh exposed to the action of the surf has bulrushes as dominant species; *Scirpus validus* occupies the deeper water often to a depth of five feet, and *Scirpus americanus* grows best in the shallower places. In those portions where the action of the surf is considerably diminished and quantities of humus accumulate, a reed swamp succeeds, consisting principally of *Phragmites communis*. The reed grass and also the cattail are the dominant plants. The reed does not occupy any particular soil level, but the cattail is usually found in the deeper water and in more exposed positions than the reed grass. Among these occur Indian rice (*Zizania aquatica*) often obscuring the associated species such as the burweed (*Sparganium eurycarpum*), and arrow head (*Sagittaria latifolia*, *S. heterophylla*),

[1]Jennings, O. E., An ecological classification of the vegetation of Cedar Point. Ohio Naturalist, Vol. VIII, 1908, pp. 291-340.

Moseley, E. L., Formation of Sandusky Bay and Cedar Point. Proc. Ohio State Acad. Sci., Vol. IV, 1904, pp. 179-238.

which forms a secondary vertical stratum. With them alternate and mingle sedges (*Carex comosa, C. aquatilis*), rushes (*Juncus canadensis*) and others. Frequently the yellow water lily may be found forming a tertiary layer, while masses of algae, duckweeds (*Wolffia columbiana*) and various diatoms, blue-green algae, pellets of *Nostoc* and other low plants nestle among them as a ground cover. Where the accumulation of humus has raised the soil above the water, thickets of willows (*Salix discolor, S. lucida; S. myrtilloides=pedicellaris, S. amygdaloides*) or thickets of buttonbush and dogwood (*Cephalanthus occidentalis, Cornus stolonifera*) follow. In the earlier stages of development the association includes, as in inland localities, *Typha sp.; Sparganium eurycarpum, Sagittaria heterophylla* and others form a secondary layer, alternating and mingling with *Carex comosa, C. aquatilis, Juncus canadensis.* The *Phragmites* association often succeeds a bog meadow (cranberry-sphagnum association) in localities where the peat is solidly grounded, in a more advanced stage of disintegration, and well drained.

These various types of associations in the shore succession are often to be seen along the shore of one lake. Correlations with soil conditions are more easily established than with any other one factor. Differences in light and evaporation affect the plants less critically as yet, for competition becomes intenser in the later stages of the succession. Of the several types, the *Phragmites* association indicates the better physical condition of the soil, favorable also for agricultural purposes.

In many cases all of these types of associations in the shore succession may pass gradually or abruptly into bogs, intrude upon one another or even alternate. The boundaries are frequently ill defined, and the various types of shore associations are often to be seen more or less clearly along the shore of one lake. At the several large reservoirs of the State they occur less promiscuously scattered than at the smaller lakes and ponds. There is considerable evidence that the disturbances observed in the groupings and in the invasion of a habitat are chiefly the result of the ice shove during winter and early spring. Exposure to wind and waves, the sandy nature of the area, and the interference by man may in part account for the lack of continuity in this association at some lakes and its absence in others.

Naturally a change in the width of the zones and in the character of the vegetation follows as the water decreases in depth during the process of filling or becomes less available. The vegetation continues to move toward the center of the lake while shoreward it is replaced by plants of another type of association. Up to this stage in the process the marginal and shore plants in the shallower water may still receive better aeration and sanitation on account of the more frequent stirrings by waves and surface current action. The water is quickly warmed, much more so than that in the deeper parts of the basin; the physical and biochemical conditions of the substratum are yet favorable for rapid growth, and any gaseous or other injurious products due to the partial decomposition of the débris are in dilutions not to inhibit functional activity of many plants. In fact their presence in small quantities carries with it a corresponding intensification in the growth rate of some plants. Nevertheless, it is interesting to note that the vegetation shows striking habitat-structures such as aerenchyma, internal air-containing spaces, respiratory roots and lenticels to secure sanitation, and that most land plants, unless they have these special reaction structures, are soon killed out. The plants invade the shallow water with constantly increasing numbers, but the soil conditions are the most important factor in limiting their distribution. In the meantime the shallow places become filled with the parts of dying plants. The deposit increases in purity as well as in thickness. Gradually its surface is raised near the water level; in deeper basins the quaking mat becomes firmer shoreward and the decay of the plant débris prepares the way for another succeeding vegetation—the true bog meadow association.

IV. THE BOG SUCCESSION

Without change of climate or of mineral salt constituents, the aquatic and marsh vegetation becomes suppressed under certain conditions. Organic processes in the substratum, as they approach the limit of favorable conditions, become of greater importance than variations in light, temperature or evaporation.

They induce the establishment of the intermediate stage, the xerophytic formation. Frequently one or more phases of the bog succession are omitted entirely, and various deviations or intercalations occur; always, however, they are replacing one another quite independently of climatic and topographic changes. The succession of associations like that of their displacement is a form of edaphic selection due to the establishment of certain species and the exclusion of others. The plants themselves are the most important factor in bringing about the change. The root systems lie mainly horizontally, near the surface of the ground, and resemble in their general features of diffuse growth, depth of penetration and behavior, several of the typical desert plants.[1] As the production of peat land by the activity of the vegetation continues, concomitant with the organic changes in the soil, there is the replacement of one type of vegetation by another.

The shoaling of the water, the lack of aeration by wave and wind, to both of which the marginal vegetation is a strong barrier, and the greater temperature exposure (tables 6-9), are characteristics which should be mentioned as in part limiting and replacing the former marginal sequence of associations. More important factors which become

[1]Cannon, W. A., Root habits of desert plants. Carnegie Inst. of Washington, Pub. 131, 1911.

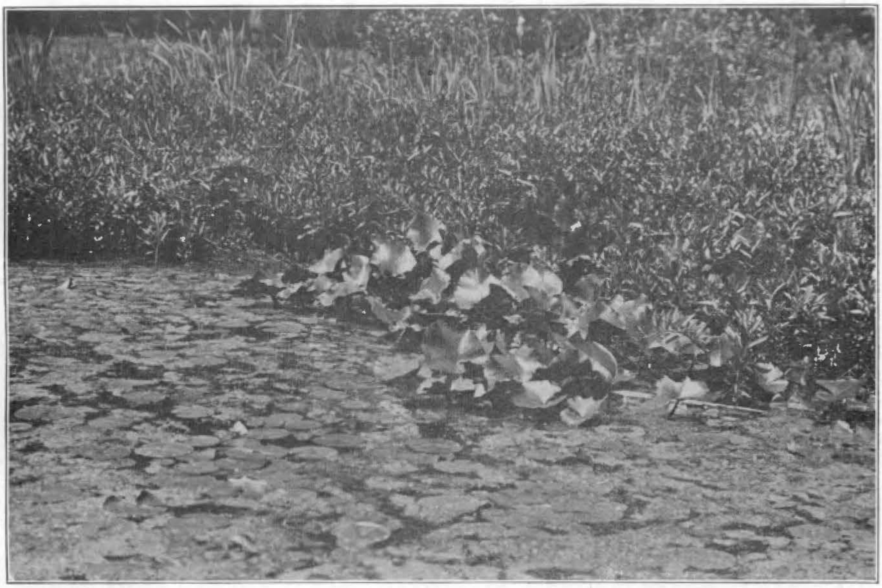
paramount with the encroachment of the bog meadow association are changes in the chemical (tables 29-30) and physiological effects (tables 10-15) of the soil water. Although the ground water table is still high and water is abundant, it is largely useless to the plants on account of the accumulation of injurious substances. These are principally due to the activity of fungi and bacteria living in the organic substratum (pp. 346-358). A great variety of these organisms, varying in kind and in number with the character of the surface vegetation, live on the starches, sugars, proteins and fibrous matter of the debris within the upper layer of the soil. There are other changes which take place during the transformation of plant tissue into peat. Of these only the more typical can be mentioned here.

A. THE BOG MEADOW ASSOCIATIONS

A bog meadow association is an open but dense and exclusive type of vegetation cover. Its vertical level is fairly uniform and varies between 6 and 18 inches; it is never more than 3 feet high. There are usually two vertical layers—the ground vegetation, which includes the mosses and rosettes of several flowering plants, and the field layer, consisting of tall shoots of the perennial herbs. Mingled with these occur isolated shrubs, scattered here and there, the forerunners of coming transition stages, whose height averages about 5 feet. In general vegetation features, in the prevailing grass-like growth form, and in anatomical structure, the plants are an ecological unit, a response to a habitat with moderate or scanty physiological water supply.

According to the preponderance of certain plant forms two types of bog meadows may be recognized. They should properly be regarded as separate associations, since they exhibit distinct differences among themselves. The one is a bog produced principally by sedges (*Carex sp.*) and other similar plants; while in the other, the cranberries and sphagnum mosses are the chief peat formers.

1. Carex-Juncus Association.—The first type of bog meadow is produced principally by sedges (see *Carex-Juncus* association). The association includes many of the species of the cranberry-sphagnum bog meadow, but in numbers rarely above a third of that of the sedges. The sedge bog meadow is characteristic of flat areas and shallow shores. The type of peat is firm, finely fibrous and felt-like in appearance. It retards drainage, and in rainy seasons retards the run-off. As the water level becomes continuously raised with the accumulation of the dominant growth, a peatbed is built up from the bottom of the successive elevations of the water level. The mechanical competition of rhizomes is sharp and the root systems mix indiscriminately. Since these conditions eliminate many species of hydrophytic plants, the peat is usually homogeneous in texture. The flora of a deposit of that character



A.—Vegetation along the border of peat depositing lakes. The zone of water-lilies is followed by swamp loose-strife and cattail. They form the border of the bog succession. *(Photograph by F. Brown.)*

B.—The bog succession: cranberry-sphagnum meadow displaced by bog shrubs (*Alnus-Rhus* association) and trees such as red maple, black ash and red elm. *(Photograph by F. Brown.)*

becomes heterogeneous only when the water level remains high or low for a long time. Sedge bogs are relatively rare and no longer typical in Ohio. They occur only in a very limited extent near Tiffin, Ayersville and a few other places. The typical vegetation is that of a *Carex-Juncus* association (p. 232). With them mingle in smaller numbers cranberries, sphagnum mosses and several other herbaceous components of the association next to be described.

2. Vaccinium = Oxycoccus marcrocarpon-Sphagnum sp. Association.—A cranberry-sphagnum bog meadow ordinarily comprises the cranberry (*Vaccinium macrocarpon*), several species of sphagnum mosses (*Sphagnum cymbifolium, S. recurvum, S. acutifolium, S. parvifolium*) which may span even the open water of small pools, several sedges (*Carex limosa, C. filiformis* and others), buckbean (*Menyanthes trifoliata*), beak rush (*Rhynchospora alba*), tall sedge (*Dulichium arundinaceum*), cowberry (*Potentilla palustris*), shield fern (*Aspidium = Dryopteris thelypteris*) and arrow grass (*Scheuchzeria palustris*). They grow in tufts and mats of varying height, form a foothold, and in occasional drier places enable sun-dew (*Drosera rotundifolia*), the pitcher plant (*Sarracenia purpurea*), tall cottongrass (*Eriophorum virginicum*) and others to come in (Plate VII, A). Here also the plants are more or less competitive, but the different depths which the root systems occupy enable the species to thrive advantageously. At a depth of eight to ten inches (20-25 cm.) the sphagnous substratum frequently contains the underground stems of *Rhynchospora alba, Dulichium arundinaceum, Menyanthes trifoliata,* also *Carex filiformis.* Higher in the soil (5-7 inches) may be found rhizomes of such species as *Scheuchzeria palustris* and *Eriophorum virginicum,* while nearer the surface is found a mixture of the root systems of *Carex limosa, C. retroflexa, Aspidium = Dryopteris thelypteris, Drosera rotundifolia* and others. Lack of space precludes illustrations or more than a brief mention of these few examples. In addition to this groundwork of plants other herbaceous constituents of the bog meadow, scattered throughout either as less abundant and secondary species, as invading migrants, or as stragglers from other associations, are the flowering ferns (*Osmunda regalis, O. cinnamomea*), several species of orchids (*Pogonia ophioglossoides, Calopogon pulchellus, Arethusa bulbosa*), several club rushes (*Scirpus caespitosus, S. cyperinus, Juncus effusus, J. canadensis, J. brachycephalus*), golden rods (*Solidago uliginosa*), asters (*Aster paniculatus*), prostrate bramble (*Rubus hispidus*), marsh St. John's-wort (*Hypericum = Triadenum virginicum*), seedlings of poison sumach (*Rhus vernix*), shrub-like alders (*Alnus incana, A. rugosa*) and stunted trees of red maple (*Acer rubrum*). Among the mosses are species of *Polytrichum, Aulacomnium, Bryum* and a few liverworts. In small open pools are aquatic species of *Hypnum,* pellets of *Nostoc* and other lower forms of plants, with a few isolated families of pickerel weed ((*Pontederia cordata*), or arrow arum (*Peltandra virginica*), arrow head (*Sagittaria latifolia*) and cattail (*Typha sp.*). These and other more hydrophytic plants are usually killed by the dense growth of sphagnum mosses and the cranberry.

This list is a fairly representative example of the vegetation structure common to the bog meadows of Ohio. In almost all essentials the vegetation is similar to the European high moor. The absence is especially noticeable of parnassus (*Parnassia caroliniana*), lobelias (*Lobelia spicata, L. siphilitica*), snakehead (*Chelone glabra*), lousewort (*Pedicularis lanceolata*), fringed gentian (*Gentiana crinita*), and the marsh bell flower (*Campanula aparinoides*) in all bog meadows except at the cedar bog near Urbana in Champaign County, a bog in Auglaize County and a few isolated swampy areas along the glacial boundary of Fairfield and Hocking counties. These plants together with the pitcher plant (*Sarracenia purpurea*) and arrow grass (*Scheuchzeria palustris*) are the first to disappear in the succession passing from the open association to that of the bog heath. The few areas in which they occur as relicts are either exceptionally favorable marshy places, ravines, or bog-situations characterized by cold springs.

Naturally a vegetation more highly diversified than that of any of the previous ecological groups is extremely rich in the variety of possible facies and societies. Though characterized by a relative simplicity of flora as compared with the climax vegetation and by a uniform physiognomy, the vegetation varies greatly in aspect at places only a few rods apart. In an extensive bog meadow the same species mentioned above alternate variously in abundance and occur here and there in separate groups. A *Dulichium sp.* society or one of *Rhynchospora sp.*, *Eriophorum sp.*, *Carex sp.*, or *Aspidium sp.* in a groundwork of sphagnum mosses and cranberries regularly derives its character from the fact that one of these plants is more numerous in certain areas than in others, the intervals being occupied by other plants showing a less characteristic response in aggregation or in numbers. Most of the secondary species exhibit no apparent preference for some one particular society. As already pointed out the minor groups of the association will depend not alone upon the dissimilar levels at which roots and shoots grow and upon the distinctness of the principal species but also upon the seasonal aspects. Thus the orchids become quite conspicuous during their time of blooming, the *Arethusa bulbosa* society in early spring, the *Pogonia ophioglossoides* society in late spring, the *Calopogon pulchella* society still later in midsummer. The goldenrods (*Solidago uliginosa, S. canadensis*) together with asters (*Aster paniculata, A. sp.*) characterize respective societies in autumn. There is in consequence an alternation of minor plant societies, and the essential identity of the vegetation in habitat form is thus broken.

Sphagnum mosses predominate in sheltered places with little circulation of air near the soil substratum. A damp air blanket usually hangs over the habitat and prevents any occasional desiccating winds from destroying these plants. Sphagnums are often found on wet sand and on rocks in moist ravines where the smaller saturation deficiency of the air is largely a matter of lower temperature. The plants grow up in tussock-like elevations; the thick soft mass is raised to a considerable height around supporting objects, more at the center than at the sides, extending at the edge of the mat and thus converting more and more of the adjoining area into soft masses of moss. The maximum height to which cushions of sphagnum can grow is limited by the vertical saturation gradient of the water content in the air, and the height to which the water will rise within the moss-mat from the general water level. This height is often more than four feet.

Around most of the lakes and ponds, the bog meadow association does not have the conditions which enable it to occupy a wide zone. The zones vary greatly in width at different places; in the majority of the localities studied the association is entirely absent. Thus far the writer has observed a fairly pure cranberry-sphagnum association only near Long Lake at Lakeville in Holmes County, near Edgerton in Williams County, near Brimfield in Portage County, and on Cranberry Island at Buckeye Lake in Licking County. Elsewhere the association is more or less completely supplanted by succeeding associations. Near Long Lake the plants occupy the habitat very completely, but clumps of the high bush blueberry (*Vaccinium corymbosum*) are seen scattered about here and there in advance of the main shrub association. In the majority of cases the formerly extensive cranberry-sphagnum marshes are now peat deposits under cultivation.

A cranberry-sphagnum mat is always sufficiently bouyant to prevent its sinking much below water level. On Cranberry Island at Buckeye Lake it is firm enough to support trees. At various places the mat is young and thin, with several feet of clear water below it. It differs markedly in its structure from peat formed by the remains of true aquatic plants and hence can be readily recognized in testborings.

The type of peat is coarse in texture and conducts water readily. With any alteration in the water level the mat of the cranberry-sphagnum bog shrinks or floats. Variations in the position of the water table do not influence the association so greatly as is often stated, nor do they offer an explanation of the xerophytic structure of the plants. On Cranberry Island bog xerophytes succeed hydrophytes upon a habitat with a prevailing high water level. Variations in the water table due to various causes range at times between 4 and 7 feet, but they do not affect the association, since the mat is floating.

The evaporating power of the air is not such as to approach the limit of favorable conditions. The average rate of evaporation is about 10.9 cc. daily, as compared with 8.1 cc. for a forested (Maple-Alder) zone, and 15.8 cc. for an open lawn on the Ohio State University campus.

The data plotted as graphs exhibit a great similarity in the general course, and show coincident and proportionate minima (7.6 cc., 3.9 cc., 12.6 cc. respectively for each station as mentioned) in early June, and maxima (17 cc., 11 cc., 21.5 cc.) in late July. The data indicate that the rate of evaporation in the bog meadow is not a sufficient cause for the xerophytic character of the vegetation; nor are the differences in the rates efficient factors in causing successions. The relation between succession and evaporation shows that the genetically higher associations control evaporation, and hence are not determined by it.

In this association the growing season is determined not by the length of period of suitable soil temperature but by the length of the period when the available water is physiologically sufficient to maintain growth. Ability to resist toxicity is essential to the successful growth of the plants in this environment. Winter temperatures below 32° F. at the one-foot level have not been found to occur in a bog meadow of central Ohio.

Acidity in the soil is equivalent to a fraction of a normal sodium hydroxide solution, but can not be associated with the injurious substances accumulating, through bacterial action and otherwise, in the peaty substratum. It is frequently stated that humus acids, such as humic, ulmic, crenic, and apocrenic, are important constituents to which peat habitats owe their characteristic vegetation. Another favorite explanation is that these acids give to peat its antiseptic property and stop the action of bacterial organisms. Humous acids are rather complex and ill-defined bodies and none of them can be said to be established chemically.

Bog water is alkaline to methyl orange, and it is of interest to note that at certain depths underneath the substratum the peat in many cases proves to be alkaline also to phenolphthalein. In Ohio peat deposits the nature of the vegetation or the presence of deleterious substances in the substratum is not in direct relation to acidity in the soil. Acidity like toxicity represents merely a stage in the decomposition of organic matter. A shallow, superficial zone of oxidation exists scarcely more than one foot in depth, beneath which the débris is charged with reducing substances of various kinds. It becomes darker in color with great rapidity when exposed to the air.

The amount of mineral salts is of subordinate significance.[1] Lime in the soil does not prevent their growth,[2] for cranberry-sphagnum meadows were until recently extensive in Mercer, Wyandot and Crawford counties overlying the Niagara and Monroe limestone formations. In Champaign County near Urbana, sphagnum grows in profusion

[1] Massart, J., Esquisse de la Geographic Botanique de la Belgique. Bruxelles 1910.

[2] Graebner, P., Die Heide Norddeutschlands. Leipzig, 1901.
Transeau, E. N., The bogs and the bog flora of the Huron River Valley. Botanical Gazette, Vol. 41, 1906, p. 32.

on peaty substrata near springs the water of which is charged with carbonate of lime. Of great interest is the observation that sphagnums are abundant in one basin overlying a limestone area as at the Dallas bog in Champaign County, and entirely absent in another basin nearby, as at Brush Lake, not more than a few miles distant.[1]

With the interlacing of the strong widespreading underground stems and roots the quaking mat becomes coarsely fibrous and denser. In places the conditions of relative stability and dryness are still more improved as the plants increase in the number of individuals and in species. After this change of conditions in the environment, produced entirely by the plants themselves, a further change in the association inevitably follows. Each stage in the vegetation succession exerts upon the habitat its own reactions, which make the physical, chemical, and biological conditions more and more unfavorable to the permanency of the occupants, but advantageous to invading plants.

The disturbance produced in the soil is not unfavorable to the dominance of the association as long as the water level is high and growth can continue on top of the accumulating débris. Consolidation of the peat material below the water surface is the controlling factor. As long as the sinking of the mat and the shrinkage and settling of the peat continue below the water level, the association persists. Its movement forward is in most cases a very slow one, dependent upon extremes in drought, in changes of the water table along shallow shores and in zones where the peat is grounded, or upon the available physiological water in the floating mat. Deficiency of mineral substances such as lime, potash, phosphoric acid, or great distance from the mineral substratum never renders it difficult or impossible for the plants to grow luxuriantly. It does not even decrease the invasion and growth of the shrubs and trees that follow as the deposit is built up. In several deposits, as at Buckeye Lake, at Edgerton, near Kent and elsewhere, the peat has accumulated to more than 30 feet above the mineral subsoil. As long as the green plants can utilize the water of the substratum and the carbon dioxide of the air to form their food, the vegetation will continue to occupy the habitat as a more or less dense cover. Starches, sugars, fats and proteins are the food of the plants necessary to their nourishment and for their full development and reproduction. The mineral salts in the soil are raw food materials but not the food of plants; they are indispensable in the formation of nitrogenous substances, but only in very small amounts, and alone would never sustain life in plants. The nitrogen compounds, the sulphates and phosphates necessary for the growth and repair of protoplasm result mainly from the decay of organic matter. The relative fertility or sterility of peat soils for succeeding plant associations depends, therefore, on the micro-

[1]Schaffner, J. H., Jennings, O. E., and Tyler, F. J., Ecological study of Brush Lake. Ohio State Acad. of Sci., Vol. IV, 1904, pp. 151-165.

scopic organisms and fungi living in the substratum, and on the mycorrhiza associated with the roots of most bog plants; they prepare the assimilable compounds absorbed by the higher plants. The differences in the relative abundance of societies at different localities should not be attributed, therefore, entirely to physical texture or to the physical water content of the substratum. There is almost universally no obvious difference in these conditions, and it is not possible to ascribe the limitation of their present distribution to any combination of climatic factors. The facts derived from experiments indicate that the cause lies in the biological processes of the soil conditions.

The characteristic growth-form of the cinnamon fern (*Osmunda cinnamomea*) in the bog meadow is distinctly an effect of a habitat with a scanty physiological soil water content. The fronds are small and held rigidly erect; the pinnules are folded with pinnæ closely pressed against the rachis. The stunted trees of red maple, alders, poison sumach and buttonbush which occur scattered, have numerous dead branches, and the ragged crown of foliage consists of a few small closely appressed leaves with restricted stomata which are often protected by a heavy cuticle. In the adjoining shrub zone these plants are tall and spreading, with fronds or leaves expanded. A number of such distinctions are observable between the vegetation of a well drained and a poorly drained bog area, and it is not difficult to draw a line between physiologically true xerophytes and the number of resistant hydrophytic or mesophytic species which are associated with them when we resort to experimental criteria. The combined effect of the intensity of light and the small unfavorable physiological water content in the substratum are the conditions which subject the plants to a difficulty in maintaining a balance between absorption and conduction, transpiration and photosynthesis. Primarily, however, the structures exhibiting themselves in the peculiarities of leaf size and leaf development are induced by physiological drought.

B. THE BOG HEATH ASSOCIATIONS

No matter how numerous the seeds or fruits brought in by wind, birds, or other agencies, effective establishment is possible only to the few plants in which there is some sort of correspondence or balance in plasticity of function or in habitat form to the life relations in the peat substratum. The soil processes are best expressed in terms of reduction action. The pioneer invaders are at first isolated, but mass invasion is not infrequent upon transition areas and tension lines. The distribution of bog heaths is, however, far more limited than that of any of the other associations in the cycle. This is largely due to the greater specialization in habitat requirements. Other plants are excluded for the reason that they can not subsist on the organic compounds arising in the substratum. If the numbers of such invaders as leather leaf (*Chamaedaphne calyculata*), bog rosemary (*Andromeda polifolia*), labrador tea (*Ledum groenlandicum*), huckleberry (*Gaylussacia baccata*), blueberry (*Vaccinium corymbosum*) or shrubby cinquefoil (*Potentilla fruticosa*) are large enough to bring about the reactions in soil and atmospheric conditions, in light, humidity, and temperature, to cause the gradual decrease or disappearance of the former occupants, a small-leafed dwarf shrub association may be seen originating. There is also a mixing of several principal and secondary species of other associations, but in total number of species the heath bog is poor.

1. Chamaedaphne calyculata Association.—The leather-leaf heath bogs are of frequent occurrence in northern Michigan, where they are found over extensive tracts growing under a variety of conditions. By far the greater number of peat bogs examined in Ohio do not now possess a typical heath association. With few exceptions the association is limited to, and more typical in, the northeastern portion of the State. Where the facies form a closed association, as at the Eckert bog north of Kent and at Ravenna in Portage County, or at the Pymatuning swamp in Ashtabula County, the botanical composition of the vegetation structure is relatively uniform and usually as follows: The dominant plant is leather leaf (*Chamaedaphne calyculata*) in low but dense and impassable thickets. It quickly covers considerable areas by sending out long underground stems from which aerial leafy branches rise at short intervals. The height reached averages usually about three feet. At about the same time appears bog rosemary (*Andromeda polifolia*), together with low blueberry (*Vaccinium vacillans*), huckleberry (*Gaylussacia resinosa = baccata*), although the latter is usually less in evidence except in drier habitat conditions. They are similar in underground growth form and are seldom competitive. Relatively unimportant and scarce are the wintergreen (*Gaultheria procumbens*) and the bearberry (*Arctostaphylos uva-ursi*). More abundantly associated are ferns (*Osmunda cinnamomea, O. regalis*), the ascending bramble (*Rubus setosus*), and underneath them a ground cover of sphagnum and polytrichum overgrown with the prostrate bramble (*Rubus hispidus*).
At the Eckert bog sphagnum hummocks to the height of three feet cluster around the leather leaf and other shrubs and trunks of small tamarack trees. Some of them were found inhabited by ants.

The vertical layering in heath associations is rather indefinite but better developed in more open places. There are from two to three strata determined by some herbs and grasses, and by mosses and lichens which occur interspersed in greater or smaller number beneath and between the dwarf shrubs.

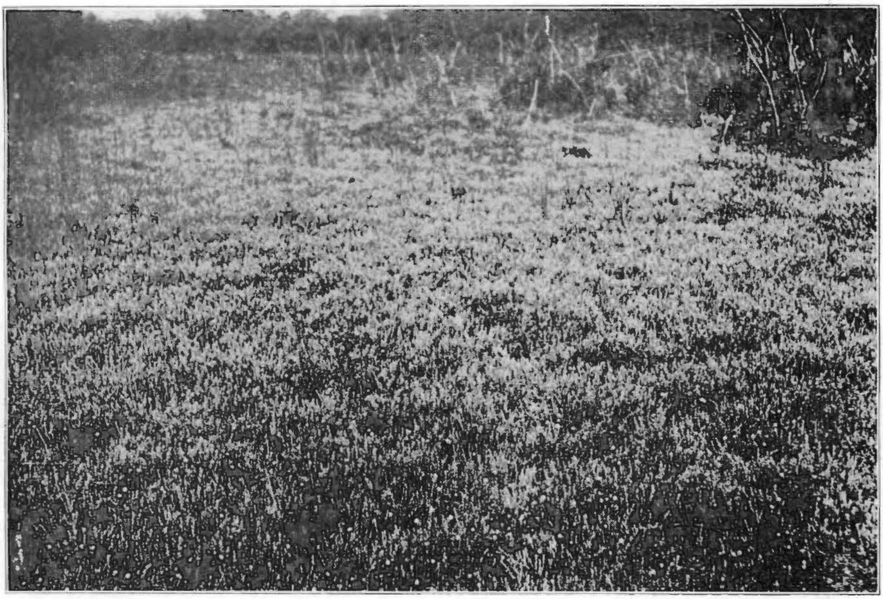
In moister and better lighted areas a low blueberry (*Vaccinium pennsylvanicum*) society alternates with the leather leaf society. In places it attains considerable importance but it is never very conspicuous. There is also a tendency to the segregation by alternation of an inner sedge society including some characteristic forms like *Carex trisperma*, *C. tenella*, *C. filiformis*, cotton grass (*Eriophorum virginicum*), with *Bartonia virginica* and mats of sphagnum mosses among which nestles the round-leaved sundew (*Drosera rotundifolia*). It is evident that the majority of the members in the *Vaccinium pennsylvanicum* society illustrate the passing phase of an earlier cranberry-sphagnum association, and that the open places are therefore to be looked upon as relicts of the former vegetation cover.

Somewhat more complex in composition are the later and maturer stages in the heath association. The *Chamaedaphne* bogs south of Ravenna, near the city limits, illustrate the following structure. Before the extensive bog area was disturbed by the laying of roadbeds for railways, the vegetation occupied typical positions around the lake. There crowded forward into the heath association winterberry (*Ilex verticillata*), mountain holly (*Nemopanthus = Illiciodes mucronata*), chokeberries (*Aronia sp.*), alders, species of arrowwood (*Viburnum sp.*) and other shrubs, followed by tamarack, red maple and others upon a peat substratum more than twenty feet in depth.

2. Potentilla fruticosa Association.—The second type of heath bog occurs more typically near Carey in Wyandot County and near Urbana in Champaign County (Plate VII, B). The shrubby cinquefoil (*Potentilla fruticosa*) predominates with the marsh shield fern (*Aspidium = Dryopteris thelypteris*) as principal species in the interspaces. The vegetation at Carey comprises scattered plants of bog rosemary (*Andromeda polifolia = glaucophylla*), swamp birch (*Betula pumila*), lobelia (*Lobelia kalmii*), goldenrods (*Solidago canadensis*, *S. ohioensis*, *S. riddellii*) and small shrubby specimens of poison sumach (*Rhus vernix*). It is interesting to note that the stinging nettle (*Urtica gracilis*) is not an infrequent member in the heath association. On the roadsides adjacent to the bog and along the drainage ditches the nettle occurs in a rank growth averaging a height of five to seven feet; it occurs in moderate quantities in the heath and does not attain a height greater than one foot.

The pure heath association extends farther into the basin than it does along the margin of it, showing there the better adjustment to positions of greater exposure and aridity. It passes into secondary burn and grazing successions, and finally gives way to a mesophytic association consisting of red maple (*Acer rubrum*), white and black ash (*Fraxinus americana*, *F. nigra*), elderberry (*Sambucus canadensis*), locust (*Gleditsia triacanthos*) and elms.

3. Gaylussacia baccata = resinosa-Vaccinium canadense Association.—Still another type of heath bog is found in the majority of our peat-depositing lakes and ponds. At Buckeye Lake in Licking County the association is a mere relict, owing doubtless to the disturbances in



A.—Cranberry-sphagnum meadow on Cranberry Island at Buckeye Lake. Cranberry in fruit.

B.—Shrubby cinquefoil meadow (*Potentilla fruticosa* association) at the Dallas Bog. White cedar (*Thuja occidentalis*) and tulip tree (*Liriodendron tulipifera*) in the backgreund.

water level and the short period in which it has been allowed to develop undisturbed. The association is characterized by a pure stand of the black huckleberry (*Gaylussacia resinosa=baccata*). In the bogs of Portage, Summit and Stark counties as well as elsewhere, the velvet-leaf blueberry (*Vaccinium canadense*), the low blueberry (*V. vacillans*), and other species of the same genus are the more familiar representatives. The association has few secondary species and varies but little in general appearance from season to season. The black huckleberry and the blueberries spread rather slowly but generally in all directions by means of their long underground vegetation shoots. The huckleberry does not fruit well at Buckeye Lake, but in other areas it has an abundance of berries. Isolated plants and ecological families arising by the radiate enlargement of the parent plant, and even communities are to be found in one bog; they have evidently been distributed by birds. As a vegetation unit it represents the least stable type of heath associations.

The reaction of the heath association upon the soil conditions of the habitat is one of the most striking features of distinction. In considering the effects of the invasion of shrubs in a sphagnum bog it is at once apparent that factors become operative which were not previously in evidence. Since the low shrubs reach a greater height than the sedges, herbs and mosses, and arise in denser aggregations above them, they are thus able to deprive the plants of the bog meadow of much light, and gradually kill them out. At the same time, the scanty, but efficient, leaf fall permits an accumulation of raw humus from above the water table which brings the humus level more and more within reach of the direct influence of aeration and weathering factors. The leaf litter acts as a mulch. Owing to its darker color the peat is more easily heated. The shading of the living ground cover prevents excessive evaporation but also efficient oxidation. Humification is still retarded, and there result various organic substances, but little available as plant constituents to other than the native vegetation of the zone.

It is still an open question to what extent bog plants require the organic compounds arising in peat soils. The assimilation of such substances is undoubtedly rendered possible through the action of the enzymes produced by mycorrhiza, bacteria and fungi in the soil. In support of this view it is important to know that certain fungi from the peaty substratum of Cranberry Island, when grown isolated in bog water and bog soil, rendered the peat available for use by agricultural plants. The experiment, which consists of the methods used in bacteriology and physiology, can be easily demonstrated (p. 354).

Several of the heath plants can thrive in more northern states in very wet cold areas, on dry sandy soil and on ordinary soil. In the opinion of the writer this departure is only possible where lower saturation deficiency in the air tends to maintain an equilibrium relation between absorbing organs and transpiration surface. When growing under conditions of greater humidity the plants respond to the change in habitat by broader, thinner and smoother leaves. This suggests that the drought or xerophytic devices serve as a protection from physiological desiccation. The aerial parts of plants are constantly losing water by transpiration, a process similar to evaporation. In most of the shrubs the absorptive capacity is small on account of the absence of root-hairs; the type of wood offers no morphological or physiological limitations to the conduction of water;[1] and the physical conditions of the atmosphere such as temperature, humidity and wind which influence the amount of water transpired, are relatively uniform and similar over wide areas. Extreme xeromorphy is found, however, in the upper layers, in the leafy canopy of the heath association. It appears, therefore, that certain disturbed relations in the soil water content are minimized and balanced by an increased thickness of the mesophyll layer in the foliage. But whatever the essential purport of the xeromorphic characters, such as small narrow leaves, well developed coating of hair, thick cuticle, whether to minimize the effects of light intensity and greater saturation deficiency of the air, or of disturbances in the admission of carbon dioxide during photosynthesis at the higher levels in which the CO_2 percentage of the vertical gradient is less than near the ground—the fact that invading plants and such cultivated varieties as have been used in experimental work in the laboratory likewise take on several of these structural variations, points to an unfavorable water content in the soil as the limiting factor. The depression in functional activity is an effect of the soil conditions encountered, which compel the plants to deal economically with the available water supply. Here again it is seen that the characteristic simplicity and growth-form of the association, and the reduced competition with other species are due to endurance and to drought resistance.

C. THE BOG SHRUB ASSOCIATIONS

The reactions of the heath association cannot be entirely unsuitable, for the soil, though physiologically unfavorable and to most plants sterile, has at the same time undergone changes suitable for certain other species. It may be that some forms of nitrifying organisms in symbiotic relation with *Alnus* and other species render the conditions for displacement more effective (Chapter X, Table 22). Eventually the heath association, whether open or closed, is replaced by a tall shrub and thicket association. Many seedlings of alders, chokeberries, poison sumach, or, if nearer the water's edge, seedlings of buttonbush (*Cephalanthus occidentalis*) and willows find lodgment in the conditions

[1]Stopes, M. C., The xerophytic character of the gymnosperms. New Phytologist, Vol. 6, 1907.

offered, so that partial occupation soon ensues, and later their complete establishment.

1. The Alnus-Rhus Association is more northern in its frequency of occurrence, yet it is the most general and constant component of the bog flora at this stage even in the central and southern parts of Ohio (Plate VI, B). The only bog area thus far noted, in which alders were entirely absent, is at Mud Lake, one and one-half miles northwest of Lakeville in Ashland County, where the alders are replaced by arrowwood (*Viburnum dentatum, V. cassinoides*). Elsewhere the chief species of the association are *Alnus incana* and *A. rugosa.* In its other constituents the vegetational structure is usually as follows: Facies, *Alnus incana, A. rugosa, Rhus vernix*; principal species, the chokeberries (*Aronia nigra, A. arbutifolia=Pyrus melanocarpa*), high blueberry (*Vaccinium corymbosum*), black alder (*Ilex verticillata*), mountain holly (*Nemopanthus=Illicoides mucronata*) and the arrowwood. Secondary species are relatively scarce except in more open situations, and are generally stragglers of previous associations. Meadow sweet (*Spiræa salicifolia*) and steeple bush (*S. tomentosa*) are relatively prominent. The root systems are at various levels in apparent relation to the water table. Various species of climbing plants invade the association at the same time with the thicket formers. The mature thickets are often covered with an impenetrable growth of tangled vines of shrubby bittersweet (*Celastrus scandens*), nightshade bittersweet (*Solanum dulcamara*), wild bean (*Apios tuberosa*), bindweed (*Convolvulus sepium*) and others. It was at times very difficult to penetrate the underbrush of the bog near Edgerton and near Atwater. The limited number of trails rendered access to many parts a matter of the greatest difficulty.

The chokeberries are particularly aggressive in occupying new territory. They advance and make new centers of dispersal by means of their long underground stems which develop vertical leafy branches. They soon overtop the lower plants and stragglers of the bog meadow, holding the entire ground as a sharply defined group in alternation. The black alder or winterberry (*Ilex verticillata*) is conspicuous in the fall with its bright red berries, constituting a distinct society.

Besides this alternation the association also exhibits layering. Zonation within itself is presented only at places where wet areas are invaded by species of willow and dogwood which form there an advance zone containing most of the secondary species. Each has a conspicuous seasonal aspect; one is determined in early spring by the willows and the other in midsummer by the dogwoods.

2. Salix sp.-Populus tremuloides Association.—It is only at shoreward places on peat in which the percentage of mineral matter is high and on shallow peat areas bordering a grassy marsh, that the accumulation of humus by the *Decodon-Typha* association is followed closely by willows or by buttonbush and dogwood without the occurrence of an intervening bog meadow or typical *Alnus-Rhus* association. The willows are of various species and often include in a conspicuous way the aspen (*Populus tremuloides*). The growth reaches a height varying between 10 and 20 feet. Some of the willows, especially *Salix myrtilloides=pedicellaris, S. candida,* and *S. lucida,* form an integral, but rather small part of the present flora of bogs.

They are confined to the proximity of tamarack and sphagnum-cranberry associations. The glaucous willow (*Salix discolor*), the black willow (*S. nigra*) and *S. bebbiana,* usually occur along small ditches which have been cut through the bogs and marshes. There is an undergrowth of ferns (*Aspidium=Dryopteris thelypteris, Onoclea sensibilis*) and other plants. The association derives many of its species from adjoining associations preceding or following it. With the decrease of the water level the willows die out so that much of the thicket-like appearance becomes constantly less prominent. The stages following this succession are more southern in relationship than northern, the final *Ulmus-Acer* association with its undergrowth belonging clearly to the deciduous forest center.

3. Cephalanthus occidentalis-Cornus sp. Association.—Although described in the bog meadow series, the buttonbush-dogwood association is found in a great variety of physiographic situations. At Buckeye Lake the border zone of plants fringing Cranberry Island is not an ecological unit; it is composed of the several types of shrub associations mentioned. At Brush Lake the buttonbush-dogwood association is much better exemplified. In almost all places visited by the writer the structure ot the vegetation is usually about as follows: dominant species or facies, *Cephalanthus occidentalis* and *Cornus stolonifera*; principal species are *Cornus paniculata, C. amomum,* swamp rose, (*Rosa carolina*), the shield fern (*Aspidium=Dryopteris thelypteris*) and frequently willows (*Salix cordata, S. lucida*). Among the secondary species are occasionally the following: willow (*Salix nigra, S. discolor, S. sericea*), sticktight (*Bidens cernua*), marsh St. John's wort (*Hypericum=Triadenum virginicum*), touch-me-not (*Impatiens biflora*), swamp milkweed (*Asclepias incarnata*), skunk cabbage (*Symplocarpus fœtidus*), spike rush (*Eleocharis obtusa, E. quadrangulata*) and *Dulichium arundinaceum.* As is usually the case the undergrowth derives many of its members from earlier associations.

Often the number of secondary accessory species is very much reduced on account of the great density of the shrub thicket or its close proximity to the water's edge. The more hydrophytic species are killed out rapidly by the shade of the encroaching shrubs. The seasonal aspects of the respective dominant and principal species are clearly defined and have been pointed out in the more typical associations. *Cornus, Rosa, Solanum* and others, all give rise to prominent seasonal aspects. The last two associations contain members more southern in distribution than northern. The association which follows more directly is not the bog forest but the *Acer-Ulmus* association. The presence of an undergrowth which belongs to the southern deciduous forest center indicates conditions favorable to a rapid final establishment of deciduous trees.

D. THE BOG FOREST ASSOCIATIONS

The displacement of a bog shrub association may occur without the intervention of any factors other than the appearance of the invading forest species.

Among the *Chamædaphne sp.* association, and at the rear of that of an open *Alnus-Rhus*, occur the forerunners of the bog forest associations. Two well marked types are easily distinguished as typical representatives of the northeastern conifer forest center, the tamarack (*Larix americana=laricina*) and the arbor vitae (*Thuja occidentalis*) associations. This type of vegetation is very important in the development of bog forests in northern states. In Ohio, however, bog conifer associations no longer reach the extensive development which they attained during the period immediately following the retreat of the ice. They are now found in a condition to be looked upon as the waning remnant of the former, more continuous evergreen forests. In the majority of the bogs the evergreen forest associations have disappeared entirely, while in others the suitable edaphic conditions for their invasion were formed at a time when the climatic conditions favored forest associations more distinctly southern in range. In general it may be stated that Ohio is located less intermediate in phytogeographical position between these two types of forest associations, that is, the northern or southern forest centers, than Michigan or Pennsylvania. The environmental conditions are no longer such as to favor habitats suitable for northern forms. The relationships of the flora of Ohio are rather complex when compared with other states. The vegetation is composed of derivatives from several centers as well as from a former but now suppressed vegetation.

1. Larix laricina=americana Association.—An advance of the tamarack association on *Chamædaphne calyculata* is well shown in the bog surrounding Kellmore Lake (Bradley Pond) in Geauga County (Plate II), at the Pymatuning swamp in Ashtabula County, at the bogs near Brimfield, Mantua and Aurora in Portage County and at several other places. Though the association is characterized principally by tamarack, there are present in fairly large numbers scattered individuals of white pine (*Pinus strobus*), hemlock (*Tsuga canadensis*) and yellow birch (*Betula lutea*), but they are nowhere abundant. In the bogs of the western half of Ohio these tree species are present very sparingly.

There are areas throughout a tamarack association in which the choke-berries, mountain holly, black alder, high blueberry and others stand thickly in varying sizes. They form a secondary layer which with green brier (*Smilax hispida*) and other climbing plants, and with the smaller trees represented in the primary layer often form a tangled, almost impassable mass. The shade is at times dense; the associated vegetation in the tertiary layer below consists largely of smaller shrubs and of shade plants among which are touch-me-not (*Impatiens biflora*), cinnamon fern, wood fern (*Aspidium spinulosum*), wild red bramble (*Rubus idaeus* var. *aculeatissimus*), violet (*Viola blanda*), and more rarely the star flower (*Trientalis americana*) and goldthread (*Coptis trifolia*). Some of these plants usually alternate to a certain extent with the layer next above or with the carpets of sphagnum, the isolated clusters of pitcher plant (*Sarracenia purpurea*), or patches of *Maianthemum canadense*, *Polytrichum sp.*, club mosses (*Lycopodium lucidulum*, *L. dendroideum*), and mats of liverworts common in more open places. They cover small areas and thus form practically pure groups of one species alone.

Near Edon in Williams County the tamarack groves are almost as dense and impassable as in 1790 when the first survey of the county was made and the vegetation noted. The association is growing on a compact peat not more than three feet thick. Beneath this layer the peat is very watery to a depth of more than twenty feet.

The tamarack bog near Mantua is of more than passing interest. The shrub layer beneath the trees contains, in addition to the plants noted above, buckthorn (*Rhamnus alnifolia*), dogwood (*Cornus canadensis*, *C. circinata*), arrowwood (*Viburnum nudum*, *V. lentago*, *V. cassinoides*, *V. dentatum*), shad bush (*Amelanchier botryapium*, *A. canadensis*), wild cherry (*Prunus serotina*, *P. virginiana*), azalea (*Rhododendron viscosum*), dwarf huckleberry (*Gaylussacia dumosa*) and black huckleberry, lizard's tail (*Saururus cernuus*) and several sedges (*Carex leptalea*, *C. folliculata*). It is thus to be seen that the association as to trees is composed of northern plants, while the undergrowth is composed about equally of northern and southern species, a number of which may be regarded as typical of the Alleghenian or eastern transition. There are a few species whose range extends far to the south.

Equally interesting is the tamarack association near Andover. It contains among others the yew (*Taxus canadensis*), Indian cucumber root (*Medeola virginiana*), *Clintonia borealis*, *Dalibarda repens*, painted trillium (*Trillium undulatum*), club mosses (*Lycopodium dendroideum*) and others.

Tamarack bogs of all stages in development may be found in Ohio. There are some with the association of conifers just developing at the edge of the lake, as at Everett Lake in Portage County (Plate I); in others the conifers have completely covered the peat basin and are now disappearing as an association. In the Eckert bog near Kent, and the "muskeag" bog in section 29, Florence Township in Williams County, the filling process is finished. In the first of the two bogs mentioned what was formerly a series of successions of bog meadow, bog heath and bog shrub association genetically related and surrounding an open lake, is now the centrally located open tamarack association following the disappearance of the lake. The area is surrounded by large tamaracks; smaller trees occur throughout the area; the seedlings are farthest in among the *Chamædaphne* species and others. The advance of the trees is from the margin toward the center.

In the Eckert bog, sphagnum hummocks rise between three and four feet above the substratum. Dome-shaped nests of ants, from a foot to two feet high, have been observed among them. They are composed within of sphagnum, smoothly covered on the outside with a granular debris of the moss and with small twigs and leaves.

It is of interest to note that the growth of seedlings and trees in the center of the bog is relatively slow. In measuring the annular rings of tamarack trees cut in the bog and comparing the results with data obtained from similar species cut at the margin of the bog, it is found that in width as well as in frequency of distribution the annual wood increment is much wider in the trees growing nearer the margin, where toxicity processes in the peat are less prominent, than in the center of the bog.

With the dominance of the conifers, peat accumulation has reached a stage in which disintegration of the surface layer is very nearly equal to the rate of the addition of debris made by the trees and their associates. These conditions gradually reach an equilibrium relation; earlier stages reappear only as there arises a marked and sufficiently long elevation of the water level. Beavers were formerly the active agents. The trees were destroyed and peat formation once more established.

2. Thuja occidentalis Association.—The second type of conifer dominance in bogs is well shown near Urbana in Champaign County (Plate VII, B). This type of bog forest association is distinctly northern in its distribution and has not been observed to occur south of the central part of Michigan. The association is not likely to succeed itself much longer in Ohio, nor will it form an important part of the deciduous forest association favored by the dominant climatic trend. It is being destroyed rapidly and the total area occupied by the association is now small. It is not difficult to prove the true relation of this element entering the vegetation of Ohio as a relict of a former more extensive plant cover. It should be regarded as important enough to merit the rank of the position with respect to normal successions.

In several places the groves of arbor vitae are dense pure stands or facies with scarcely any undergrowth. The association has only a single vertical layer in which the lowermost branches of the component individuals bear a common spacial relation to light. The ground is littered with cedar foliage and only occasionally small sprouts of the chokeberry (*Aronia arbutifolia=Pyrus melanocarpa*), and stunted seedlings of yellow poplar (*Liriodendron tulipifera*) or small plants of the spice bush (*Benzoin æstivale*), alders and woodbine are visible; generally there are no members of a subordinate species other than a few mosses and liverworts. In more open stands in which the effects of fire and cuttings are still present the arbor vitae is found in association with the red maple (*Acer rubrum*), yellow poplar (*Liriodendron tulipifera*), black ash (*Fraxinus nigra*), white walnut (*Juglans cinerea*), sycamore (*Platanus occidentalis*), and wild cherry (*Prunus serotina*). The undergrowth is not only numerous in species, but of exceptional height and in five layers. The poison sumach (*Rhus vernix*) reaches frequently a height of twenty-five feet. Other members of this structural part of the association, and determining more specifically the physiognomy of the layer, are the alders (*Alnus incana, A. rugosa*), the winterberry (*Ilex verticillata*), the chokeberry (*Aronia arbutifolia*), and the round leafed dogwood (*Cornus circinata*). The inferior layers, which seem to be entirely determined by the density of the mixture of facies, are really overlapping communities of woodland and bog plants. There seems scarcely any relation to habitat factors. Seedlings and sprouts occur in all directions, in various degrees of abundance, and only the less hardy plants lose ground, thus producing examples of an indiscriminate alternation. The spice bush (*Benzoin æstivale*) is only of relatively less importance in the second stratum of bushes to the red bud (*Cercis canadensis*) and the elderberry (*Sambucus canadensis*).

The subordinate position with regard to the taller species is occupied by the cinnamon fern (*Osmunda cinnamomea*), the meadow rue (*Thalictrum dasycarpum=purpurascens*), the spikenard (*Aralia racemosa*), the bladder fern (*Cystopteris bulbifera*) and touch-me-not (*Impatiens sp.*) With them in varying abundance occur, as a lower herbaceous layer, the maiden-hair fern (*Adiantum pedatum*), the dwarf raspberry (*Rubus triflorus*), wood ferns (*Aspidium cristatum*), miterwort (*Mitella diphylla*), wakerobin (*Trillium erectum, T. grandiflorum*), false Solomon's seal (*Smilacina trifolia*), violet (*Viola blanda*), the star flower (*Trientalis americana*), the Indian cucumber root (*Medeola virginiana*), manna grass (*Glyceria torreynna*), and others.

In many places the various shrub layers immediately below the trees interpose as dense screens. These are often of sufficient density to reduce the light to a diffuseness which leads to frequent modification and a consequent rearrangement of the individual plants in the ground stratum. The number of such plants present is not large; they are all past flowering when shade conditions become extreme. The little mayflower (*Maianthemum canadense*) and various mosses and liverworts are the more resistant members of the living ground cover; they tend to disappear only when the shade condition approaches a light value similar to that of the pure stands of cedar.

V. THE MESOPHYTIC FOREST SUCCESSION

As the soil processes move toward the center of a filled-in basin, and the bog conditions become eliminated, the advance of associations continues toward the center also (Fig. 13). The direction and the rate of the movement vary but little from the slow progressive changes in the substratum. Many of the earlier associations are thus preserved in part for long periods of time. But with the extinction of the one the relationship with the other alters.

In northern Michigan the tamarack association is succeeded by pines (*Pinus strobus*) and black spruce (*Picea mariana*) which appear simultaneously and seem equally well adapted to bog conditions. The spruce is absent in Ohio because of climatic conditions. However, arbor vitæ, which is also more northern in distribution and occurs mixed with tamarack and balsam, is found, as has been stated, in isolated areas considerably south of its present northern range. Tamarack is so little tolerant of shade that it lasts but few generations. Any broad-leaved tree in overtopping tamarack generally kills it out. An indication of the future development of vegetation is well shown in the numerous small saplings and young trees of red maple, ash and others able to develop in shade. It may naturally be inferred that the deciduous forest will eventually crowd out the decreasing number of conifers. Rarely is a growth of tamaracks, birches or poplars followed by trees of the same kind unless the association is open, or growing on a substratum in which the progressive changes in the substratum are slow or in which the water table is near the surface.

The reaction of the deciduous invaders upon the habitat consists mainly in the addition of leaf humus. But a number of new ecological factors come into play. They are of importance in the reactions upon the conifers as well as upon the animal life associated with them. Fluctuations of the water level are among the efficient conditions in producing changes in the conifer bog forest. The aeration of the substratum depends essentially upon the lowering of the water table. With the descent of the ground water there follows a more thorough decomposition and oxidation of the injurious organic matter accumulating during periods of flood. Moreover, the fact must not be overlooked that other changes in the properties of peat soils are associated with the corresponding ones in leaf litter and in vegetation cover. The annual leaf fall covers the substratum with a visibly thicker layer of vegetable material rich in organic matter. The layer of leaf mold is now kept wet by the upward movement of water from below the surface. Temperature, aeration, texture and structure including water capacity, facility of percolation, power of raising water, all of which are greatest in peat, assume an importance increasingly favorable to the incoming vegetation. Associated with these changes are the increase of oxidizing bacterial organisms and the increased amount of ammonia, amides and other organic matter in peat available to plants by the action of fungi and mycorrhiza. The trees are surface-rooted. The zone of oxidation in peat soils, though more effective, is still shallow and the roots do not penetrate to a depth greater than one foot. They spread out in all directions from the trunks of trees, but are of sufficient size and length to give support and to withstand the strains due to wind.

It would seem on account of the great difficulty experienced in extracting the water held in peat by any means except high temperature, that the lower water table would determine the succeeding association to be the most xerophytic, and that any tendency to excessive transpiration accompanied by slow absorption from the soil would lead to more highly developed protective features against the loss of water. However, the increased shade of the trees during summer and autumn checks extremes in evaporation from the soil. Lower saturation deficiency with lower average temperatures prevail throughout the growing seasons (p. 304). Through the combined action of these factors there is a corresponding rearrangement in the vegetation. The gradual invasion of deciduous trees and the gradual dying off of conifers eventually lead to the complete extinction of bog conditions, to stability, and to the permanent occupation of the habitat by an association characterized as the climatic unit of Ohio forests—the predominance of maple, ash, oak, elm, walnut and others. As examples of mesophytic types of bog forests the following few cases are cited:

Acer-Fraxinus-Ulmus Association.—The tamarack bog northwest of Big Lake in Defiance County contains elm (*Ulmus fulva, U. americana*), black walnut (*Juglans nigra*), swamp hickory (*Hicoria minima = Carya cordiformis*), tulip tree (*Liriodendron tulipifera*) and others. Azalea (*Rhododendron viscosum*) is an occasional constituent in the shrub layer beneath the trees.

The appearance of black ash and tulip tree in the cedar bog in Champaign County is another typical example of an incoming forest association, the species of which attain their best development far to the south.

Elm, tulip tree and black gum (*Nyssa sylvatica*) are frequent members of the tamarack bogs in several localities of northeastern Ohio.

In a few bogs of central Ohio *Magnolia acuminata, Ostrya virginiana, Asimina triloba, Celtis occidentalis, Amelanchier canadensis* are found mingling with the northern components. They are typical examples of an incoming forest association, the species of which attain their best development farther south. For example, at Bradley Pond (Kellmore Lake) in Geauga County the tamarack bog with its northern components (*Betula lutea, Pinus strobus, Tsuga canadensis*) is completely surrounded by a deciduous forest association consisting in part of maple, ash, elm, magnolia (*Magnolia acuminata*) and others, with an undergrowth of shrubs among which occur the azalea, wild cherry, shad bush, ironwood, pawpaw, juneberry and others, and the spice bush (*Benzoin æstivale*).

At the Brimfield bog and at Mud Lake in Summit County the conifer association is completely eliminated. The vegetational structure of the forest association has no longer evergreen components. Only deciduous trees figure prominently on the firmer parts of the peat deposit. The typical plants are red maple, elm, ash and walnut with an undergrowth of arrowwood, high blueberry (*Vaccinium corymbosum*), spice bush, wild cherry and others. Less than a half mile north of Mud Lake a tamarack grove with yellow birch, apparently segregated from the lake at an early stage, makes a very marked contrast to the floristic composition which maintains itself nearer the lake. The anomalous feature of the "Black Swamp," in which bogs and peat deposits were occupied entirely by elm, maple, black ash and others, instead of tamarack, has been noted in the preceding chapter.

SECONDARY SUCCESSIONS

There are a number of secondary successions in peat deposits which owe their origin to human agency. Of these, fire, drainage and cultivation are the most significant in complicating natural successions by reverse movements or by hastening stability. Fires usually occur during the resting period in autumn and winter. Drainage and denudation do not result in the complete elimination of the previous vegetation. The living parts of herbaceous and shrubby plants are underground and thus the succession initiated after clearing consists of pioneers derived to a large extent from the original meadow and shrub association. They reëstablish themselves in a much shorter time on soils in which the physical conditions approach those of the bog meadow and bog shrub. Breaking done on peat soil occupied by bog forests or mesophytic forest species will result in the establishment of a vegetation characteristic of mineral soils. The botanical structure is chiefly made up by ruderal invaders, capable of rapid mobility and establishment; the chance for the usual sequence of successions then becomes remote. Fungus diseases are of minor importance in modifying the vegetation cover. Reverse courses of development, retardation, or the hastening in the sequence of successions often occur when for any reason drainage, drought, shrinkage of the peat soil, or excessive precipitation produce variations in the available water (page 199). Bogs of that character present a disjointed distribution and a confusing diversity.

Fire.—In the majority of bog areas examined the early stages of fire succession do not vary greatly. During the year following the denudation of the habitat many shoots arise from the uninjured rhizomes of ferns. The clumps of shield fern, cinnamon fern and flowering fern receive apparently but little injury. These are followed by the chokeberries, mountain holly, the high-bush blueberry and others. In places where the damage has been very great these plants do not re-enter. They are followed by types of successions more characteristic of burned-over areas. In sufficient abundance to dominate during the seasons are especially the nettles, touch-me-not, cattails and sedges (*Scirpus cyperinus*). There is more or less of a commingling of the different societies; with them are associated the evening primrose (*Oenothera biennis*), willow herb (*Epilobium coloratum*), spindle tree (*Evonymus obovatus*), arrow-leafed tear thumb (*Polygonum sagittatum*), occasionally virgin's bower (*Clematis virginiana*) and several goldenrods.

On the northwest side of the New Haven marsh in Huron County, fires have swept repeatedly over a large area of the peat basin. This marsh is the second largest peat deposit in Ohio, covering an estimated area of 12,000 acres. It has the appearance of a large grassy prairie with clusters of trees and bushes forming islands sharply marked off from one another. Tickseed sunflower (*Bidens trichosperma*), blue vervain (*Verbena hastata*), and ragweed (*Ambrosia trifida*) predominate in the area severely burned over. Boneset (*Eupatorium perfoliatum*), goldenrod (*Solidago canadensis*), and sedges (*Carex lurida*) are less abundant. In areas of slight surface fires the vegetation consists principally of shield fern, cinnamon fern, flowering fern, cotton grass (*Eriophorum virginicum*), beak rush (*Rhynchospora alba*), bog rush (*Juncus canadensis*); scattered among these are small shrubby trees of poison sumach, wild rose, meadow sweet, chokeberries, willows (*Salix discolor*) and poplars (*Populus heterophylla, P. tremuloides*). In some places spike rush (*Eleocharis palustris, var. glaucescens*), and in wetter places twig rush (*Cladium mariscoides*) are the dominant plants and give character to the area. In many sections the flowering ferns occupy the area to the exclusion of other plants, while along the southern border of the marsh dense growths of the reed (*Phragmites communis*) are more common and spread widely over the surface. In low parts of the marsh bluejoint grass (*Calamagrostis canadensis*) forms a conspicuous society; in higher places shrubs like dogwood (*Cornus paniculata, C. stolonifera*), elderberry, trumpet weed (*Eupatorium purpureum*), meadow rue (*Thalictrum revolutum*), ferns and goldenrods (*Solidago lanceolata, S. canadensis*) alternate indiscriminately. In the unburned portions of the marsh the vegetation consists of high blueberry thickets (*Vaccinium corymbosum*), chokeberries, arrowwood and others which alternate with mats of cranberry and sphagnum. In other spots a bog meadow is more clearly defined but the association is frequently overgrown and suppressed by the prostrate bramble (*Rubus hispidus*) which even covers small bushes of *Salix myrtilloides=pedicellaris* and similar shrubs. The climax stages of the fire succession, however, are more southern than northern; the *Acer-Ulmus* forest, though in early open stages, is becoming more prominent with associated species of southern relationship.

Cultivation.—As the soil is brought under cultivation, fodder grasses, like timothy (*Phleum pratense*), red top (*Agrostis alba*), blue grass (*Poa pratensis*), clover (*Trifolium* sp.) and others, make their appearance in the adjoining unticultivated bog areas. Weeds become particularly numerous in the drier places. Representative species are the small ragweed (*Ambrosia artemisæfolia*), pigweed (*Amaranthus retroflexus*), besides others which have been mentioned in the pasture association (pp. 33, 234).

Conclusion.—From the preceding account, it seems beyond doubt that peat formation, and the whole course of development and replacement of plant associations, and of component species, stand in response to the environment. In the north, bogs are correlated chiefly with great atmospheric humidity and rather low soil temperatures; in the southern latitudes, however, the formation of bog land is restricted to favorable topography and biochemical conditions in the soil. The vegetation of these deposits is at present in a retrogressive phase (p. 198), accelerated in part by physiographic changes and in part by the invasion of southern plants.

Two great, relatively wave-like and integrating phases of vegetation successions define themselves rather clearly: (1) the climatic successions, associated with the succession of geological periods and of which the migration of plants accompanying and following the retreat of the glaciers is an example; (2) the edaphic successions, in which the the replacement of one type of vegetation by another has resulted from changes in topography and a biochemically diminished water supply.[1]

In the peat depositing areas that arose at the close of the glacial period, as in those of today, the plankton vegetation first develops; where deeper water is present, there spread *Chara*, *Ceratophyllum* and others; while nearer the margin, on the surface of the water, rest the leaves of *Potamogeton*, water lilies and others. In shallow, flat basins, and along the shores of deeper bodies of water, reigns a marsh vegetation, consisting of grasses and reeds, which prepares the way for meadows and willow bushes. In the course of time the remains of all these kinds of plants accumulate at the bottom of the depression, so that the vegetation is forced to advance from the margin to the open water in the center, or grow upward from the bottom, as drainage is retarded and the water level rises. But the debris soil becomes physiologically unfit for the hydrophytic formation and for marsh plants, and another type of succession thus follows.

[1]See in this connection Cowles, H. C., The Causes of Vegetative Cycles. Bot. Gaz., Vol. 51, 1911, pp. 161-183.

The intermediate stage, the xerophytic formation, has a greater variety of conditions, leading to a more diverse and varied development flora and associations. Without change of climate or of mineral soil constituents, aquatic and marsh vegetation is suppressed, and the area of lakes and ponds diminishes. Too great stress cannot be placed

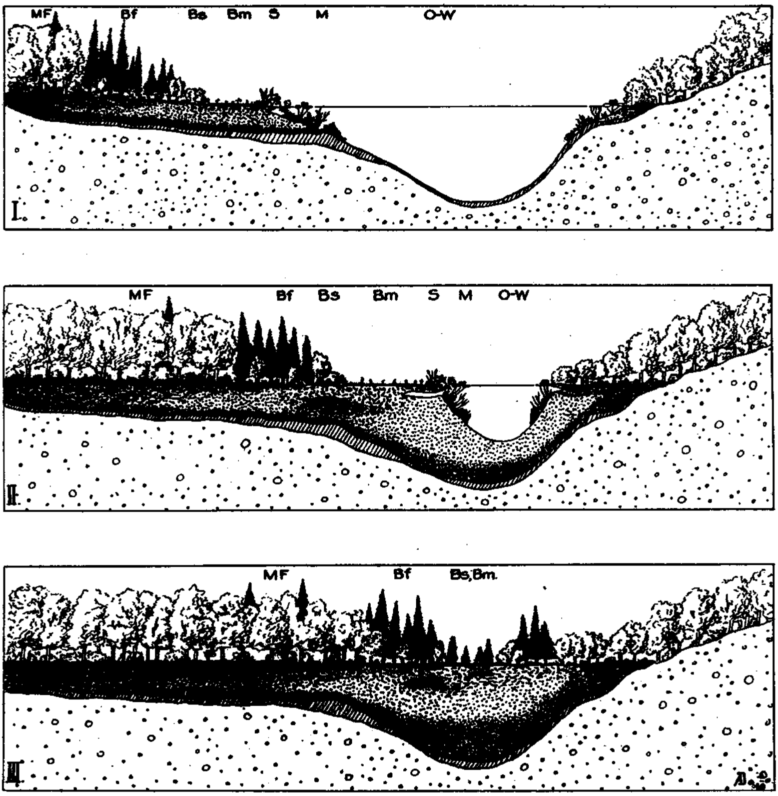


Fig. 13.—Diagram illustrating stages in the origin of peat and marl deposits in lakes. The several plant associations of the Bog Series, displacing one another, belong to the following major vegetation groups:—(1) O. W.—open water succession; (2) M.—marginal succession; (3) S.—shore succession; (4) B.—bog succession, comprising the bog meadow (B. m), bog shrub (B. s) and bog forest (B. f); and (5) M. F. —mesophytic forest succession.

upon the fact that biological processes in the substratum are of the most profound importance, and that the accompanying differences in the amount of available water exercise the decisive influence. The grass meadow is thus converted to a bog meadow, which later gives way to bog heath, finally to be displaced by bog shrubs and bog forests. The most noteworthy of the associations, in point of biological and physiological problems, are the bog meadow and the bog heath. Frequently, phases of the intermediate stage are omitted entirely, and various deviations or intercalations occur; always, however, the associations are replacing one another quite independently of climatic or topographic changes.

Thus the production of land by the activity of vegetation continues, and at the same time, with the biochemical and physical changes in the soil, is the displacement of one type of vegetation by another. The time factor involved in the invasion of a plant group is usually much shorter than that for its displacement and disappearance. But reverse courses of development often occur, when for any reason the amount of water in the soil increases or decreases rapidly. Prolonged drought, excessive precipitation, the work of man and animals, destroy much of the established vegetation cycle. The area then lies open to colonization by any association efficient to establish itself.

The filling in of a lake or pond is only one step in the genetic development of vegetation. The final stage, the mesophytic formation, arises in part from the varying relations between trees, light and evaporation. In constituent species the mesophytic bog forest corresponds to the prevailing climatic conditions of Ohio. It is a deciduous forest, which in its larger features illustrates homogeneity, but not on account of the dominance of a few species. The kind and proportion of trees differ greatly, but in type and aspect they are essentially uniform. The homogeneity is one of space, rather than of time.

Changes continue in topography, in soil processes, and very likely in climate. Migration is still taking place among plants and animals, with the extension of the more plastic organisms into endemic associations, and into new conditions. New plant associations thus arise by the addition of new species and by differentiating into divergent lines under the influence of external circumstances; by reacting and therefore deriving more advantage from these conditions. They maintain themselves in more or less definite geographical distribution. In turn, they institute changes; the reactions are followed by subsequent successions, and by modifications in the functional response of individual members, with the elimination of all plants having a small survival value. Thus we see plants and their habitats appear and disappear, related as coördinate features of a united activity throughout a developmental process. The history of many species shows that further development can only take place within certain narrow limits, and that morphological differentiation and the struggle for existence lead more frequently to defeat than to survival. It is therefore an open question whether in the future ages it will be possible for some plants of certain genera and some associations to continue to advance and to react advantageously.

The successions from the aquatic type to forests are determined by natural causes, and epitomize an ancient cycle. From one point of view,[1] the environment is assumed to be a passive condition; through its selective influence it can only indirectly modify vegetation with its many indefinite but innate and small, or sudden,[2] and great changes in individuals. From another point of view,[3] external conditions are assumed to be the direct and real cause of the increasing complexity of vegetation in structure and in social units. Through our analysis of the historical and physiological-ecological situation, we are able to see more clearly in what manner both factors in the process are themselves activating, modified and readjusted, as conditions and as causes. Either may thus induce progressive or retrogressive changes. It is also to be seen that, since the new phase grew out of the old, it can not be wholly alike that from which it came, or the same in any one series; the process is the one great cause, and the condition, of all the stages and the phases of vegetation successions, every part of which is a result and an influential factor of the organic relation.[4]

Such are the more important working principles in physiological ecology. Another point of considerable importance concerns the relation of the observer himself. As a systematist, he is endeavoring to define his subject matter in terms of types and species; as an ecologist and physiologist, he is at the same time endeavoring to reconstruct his conceptions so as to admit of a more comprehensive knowledge of the origin and nature of habitats, of plant associations, of plant response and of plant structure.

[1]Darwin, C., Origin of species. London, 1859.
[2]DeVries, H., Die Mutations Theorie. Leipzig, 1901; Korschinski, S., Heterogenesis und Evolution. Flora, vol. 89, 1899.
[3]Lamarck, F., Philosophie geologique. Paris, 1809.
[4]Spencer, H., Principles of Biology. New York, 1898.

CHAPTER VII

THE ANCIENT PEAT DEPOSITS OF OHIO AND THEIR ECOLOGICAL CONDITONS FOR GROWTH[1]

General Remarks.—It is generally agreed that plants are more or less advantageously suited for the conditions in which they live, and that the life relations between plants and their habitats are an outcome of certain definite processes linked inseparably with the past. Whatever the possible method of evolutionary advance, whether under pressure of unusual environmental conditions, or of different inherent and irreversible limits of organic variability, the behavior of plants under experimental tests will continue to contribute generalizations of real interest and importance. The facts and conditions of the present alone can aid in the interpretation of the past.

The comparatively abundant information, which we possess, as to the present vegetation in aspect, form, structure and function, as related to differences in physical, chemical and biological factors, is in striking contrast to the absence of a correlation of similar data as regards environmental conditions during geological periods. From the point of view of ecology, the vegetation conditions of the past are of considerable value, whatever the method of endeavor to understand the factors which the fossil plants record. Those who have confined their ecological study to the environmental investigations of the present must sooner or later test and supplement their investigations by reference to the past. And the aim should be to reproduce not only an accurate fragment of botanical history from the study of fossils and their respective strata, but to point out the particular physical conditions under which the plants of the Coal measures grew, and the succession of plant associations within the ancient swamp area. To correlate structural characteristics with physiological conditions of growth it is necessary to apply the knowledge of relations gained from living plants. Whether or not the data can be accepted as sound links in the chain of evidence, rests largely on the value of the experimental work at hand, and on the degree with which they interpret many apparent anomalies.

The limiting environmental conditions which characterize bogs (Chapters VIII-XI), and the structural features and functions of the vegetation peculiar to them, have seemed to the writer of sufficient

[1]The larger part of this chapter appeared with permission of the State Geologist, in the Ohio Nat., Vol. 11, 1911, pp. 312-331, and in the Am. Jour. Sci., Vol. 32, 1911, pp. 33-39.

interest to invite attention to an inquiry on the probable cause of the xeromorphy of many of the carboniferous plants which lived in swampy areas. The present chapter is intended, therefore, as a continuation of the ecological studies on the origin and formation of Ohio peat deposits, and the succession of plant associations within a peat deposit-

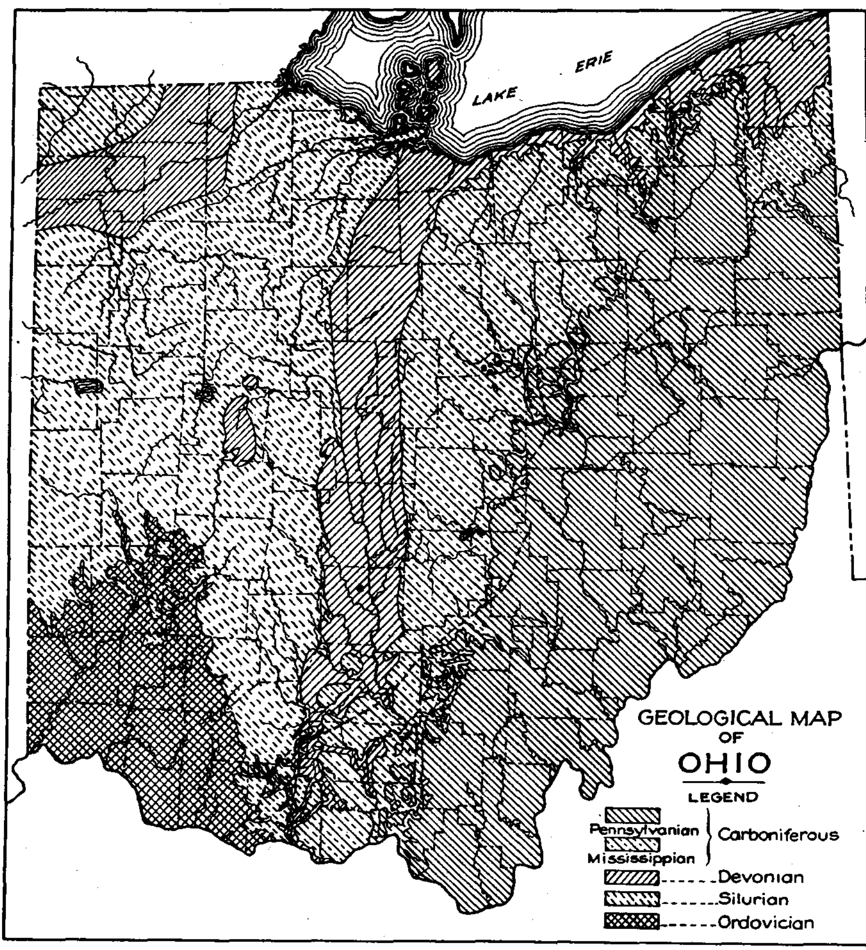


Fig. 14.—Geological Map of Ohio. The Ordovician, Silurian and Devonian consist each of shales and limestones; the Carboniferous of conglomerates, sandstones, shales, limestones and coal.

ing basin. The problems involved in the following discussion are by no means to be solved within the limits of this chapter; merely an adjustment of perspective is made, leading from a consideration of the fossiliferous plant remains of the Coal measures of Ohio.

In attempting to sketch an outline of the geological history of Ohio, it is obviously impossible to go into any details, or to follow closely the development to the present. At most, only the briefest introduction can serve, and only a general resumé can be noted. For the specific Geology of the State and a fuller treatment of the subject, the reader is referred to the volumes of the Geological Survey of Ohio and to the literature here cited.

Were we to make a rock section deep enough to reach to the lowest limits of the known stratified deposits, to the great foundations of the continent, the geological strata underlying the State would show as a stage of early growth a predominance of limestone and shale in the lower half of the section, and, as a stage of relative maturity, widespread horizons of sandstone and conglomerate in the upper half. The strata belong to five principal divisions or ages, which named in ascending order are as follows: Lower Silurian or Ordovician; Upper Silurian; Devonian; Sub-carboniferous or Mississippian; and Carboniferous, Pennsylvanian, or Coal measures (Fig. 14). Over all the State, except the southeastern part, these are covered by heavy beds of clay, sand, gravel and boulders, which together constitute the glacial drift. No evidences have been found in Ohio of that group of strata below the Ordovician, known as the Cambrian, and pre-Cambrian (Laurentian, Huronian and Keweenawan), or the great series of systems above the Carboniferous, comprising the Mesozoic and Tertiary time divisions. They either left no record within the limits of the state, or much erosion must have taken place immediately succeeding their formation.

Each of the rock systems is again subdivided, and inasmuch as the new stratigraphical divisions are coming into use more generally, and are replacing the geological names of the older surveys, the following table taken from Bulletin 7,[1] has been added to show the place in the scale, the relationship of old and new names, and the thickness assigned to the various formations:

[1]Prosser, C. S., Revised nomenclature of the Ohio Geological formations. Geol. Surv. Ohio, Bull. 7, 1905.

TABLE 4.

Geological Scale of Ohio.

Orton, 1895.	Prosser, 1905.	Thickness.
Glacial drift.	Alluvial and Glacial.	0–5 0′
Upper Barren Coal Measures.	Dunkard formation.	525′±
Upper Productive Coal Measures	Monongahela formation.	200–250′
Lower Barren Coal Measures.	Conemaugh formation.	400–500′
Lower Productive Coal Measures	Allegheny formation.	165–300′
Conglomerate Group.	Pottsville formation.	250′±
Sub-carboniferous limestone.	Maxville limestone.	25′±
Logan group.	Logan formation. Black Hand formation.	100–150′ 50–500′
Cuyahoga shale.	Cuyahoga formation.	150–500′
Berea shale.	Sunbury shale.	5–30′
Berea grit.	Berea grit.	5–175′
Bedford shale.	Bedford shale.	50–150′
Ohio shale. { Cleveland shale. Erie shale. Huron shale.	Ohio shale. { Cleveland shale. Chagrin formation. Huron shale.	300–2600′
Olentangy shale.	Olentangy shale.	20– 35′
Upper Helderberg or Corniferous limestone.	Delaware limestone. Columbus limestone.	30– 40′ 110′
Lower Helderberg limestone, or Waterlime.	Monroe formation. { Lucas limestone. Sylvania sandstone. Tymochtee member (?)	50–600′
Niagara Group. { Hillsboro sandstone Guelp or Cedarville limestone. Niagara limestone. Niagara shale.	"Niagara Group." { Hillsboro sandstone. Cedarville limestone. Springfield limestone. West Union limestone. Osgood beds.	150–350′
Clinton limestone.	Clinton limestone. Belfast bed.	10– 50′ 50–150′
Medina shale.	Saluda bed.	20′±
Hudson River Group.	Richmond formation. Lorraine formation. Eden shale.	300′± 300′ 250′
Utica shale, not seen in outcrop.		
Trenton limestone.	Trenton limestone.	130′

The Lower Silurian or Ordovician.—The Lower Silurian or Ordovician system includes the lowest of Ohio's stratified and fossiliferous rocks, the Trenton limestone and the several formations of the Hudson River group. They suggest that a broad but shallow arm of an ancient ocean then covered Ohio.[1] As in the following geologic periods, the sediments were derived from the various rocks carbonated, oxidized, and exposed to erosion and solution, the beds of limestone representing for the most part an accumulation of comminuted particles of shells and lime-secreting plants in a clear sea, and the shales representing the deposits of mud made in still water nearer the land. The adjacent lands were probably too low or too far away to yield abundant sand or permit wave-action sufficiently vigorous to keep the mud from settling. Comparatively few fossil plants of Ohio have been obtained from the geological formations of this period,[2] but the records of the life of the era in the United States and in Europe, though meager, are sufficient to indicate that development of life was well advanced long before the known strata were deposited, and that less diversity of climate existed than now. The testimony of the ancient organisms implies nearly uniform soil conditions. The plant forms, which in rocks must necessarily be rare as fossils, were relatively simple, living along the shore and in open water in definite zones, and appear to have varied with the nature and the slope of the bottom, the depth and clearness of water, etc., much as it is today. Immense quantities of microscopic unicellular plants were undoubtedly present as plankton in the protected bays with sandy and muddy bottoms to form the food supply for the large and varied fauna of that time. At the close of that period a folding resulted in an uplift of a broad, flat island-like area about Cincinnati. This arch known as the Cincinnati axis trended in a northeasterly direction from Tennessee and Kentucky to the lake basin into Canada. From that time on Ohio was nearer sea-level and in places the land areas were so far elevated as to allow sluggish streams and basins, bordered by plants.[3]

The slope of the oldest land in Ohio was toward the southeast, and the surface flow must have been in the same general direction. The ancient rivers flowed around the island and drained from it toward the northwest. The currents seem to have been the progenitors of many of our present rivers.[4]

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[1]Chamberlin, T. C., and Salisbury, R. D., Geology, New York, 1906.

[2]Newberry, J. S., On the so-called land plants from the lower Silurian of Ohio. Am. Jour. Sci. 3rd S. Vol. 8, 1874, pp. 110-113.

[3]Lesquereux, L., Land plants recently discovered in the Silurian rocks of the United States. Proc. Am. Philos. Soc. Vol. 17, 1877, pp. 163-173.

Claypool, E. W., On the occurrence of a fossil tree in the Clinton limestone base of the Upper Silurian of Ohio. Geol. Mag., Vol. 2, V, 1878, pp. 558-564.

Foerste, A. F., An examination of Glyptodendron, Claypole, and of other so-called Silurian land plants of Ohio. Am. Geol., Vol. XII, 1893, p. 133.

[4]Tight, W. G., Bownocker, J. A., Fowke, G., The Preglacial drainage of Ohio. Ohio State Academy of Science, Special Paper No. 3, 1900.

The Upper Silurian.—The Upper Silurian period includes the Saluda and Belfast beds, the highly crystalline Clinton limestone, the several elements of the Niagara group, and the Monroe formation. It extended over a vast period of time, pointing to oscillations of level which covered wide ranges of latitude. In Ohio, the living forms which inhabited the ancient sea belong exclusively to the lower animals and plant species. Only sea life existed. No traces of a land vegetation and no remains of vertebrated animals, or of a fresh-water fauna and flora have been discovered. "Seaweeds and sponges, star fishes, and stone lilies of exquisite construction, corals in great variety, and molluscan shells, were so abundant and so crowded as frequently to constitute the entire substance of the rock. Many species of trilobites are found in all portions of the bedded rock, and in its weathered exposures. The general character of these fossils indicates that the beds were formed at the bottom of a deep sea. No mark of shore lines or shallow water occurs to question this inference." But the upper surfaces of the rock layers, in places, have been found covered with ripple-marks. Their presence indicates the later existence of comparatively shallow water, and suggests the action of tides. In some localities, mud cracks suggest that the water must have been shallow enough to permit exposure of the sea bottom. The great lagoons and inclosed salt-water basins which were present suffered rapid evaporation. They are signs indicating that an unusually arid atmosphere prevailed. The severity of the conditions restricted life almost wholly to the lowland, and the shore of other more favorable regions. Probably the arctic regions were then the most favorable for growth and development. The fossil plants are few and at times of doubtful affinity; the data are altogether inadequate to give any idea of the vegetation and its ecological conditions for growth. This relative absence of fossils, together with the character of the sediments, the frequent æolian crossbedding and mud-cracks are the mark of periods of exposure; they point to near-shore deposits, if not to land origin, and to conditions of aridity with tropical climate. This does not mean, however, that a prolific vegetation, perhaps of an advanced order, did not exist. Though nothing that can be called a land flora existed, or at least is yet known, the plants of the following period show such marked differentiation and the ancestral relations are so uncertain, that a long previous history, or else a rapid evolution and extinction of intermediate forms would be the only alternatives on which to base an interpretation. A number of species common to Kentucky, Michigan and some parts of Europe have been described; among them are *Buthrotrephis ramulosa*,[1] and *Trichophycus venosus*, regarded as a plant from the Eden and Lorraine formations. The animal fossils have many characteristics in common with the European Silurian.

[1]Miller, S. A., (Description of Species). Cincinnati Quarterly Journal of Science, Vol. I: 235, 1874; Vol. II, 1879, pp. 24-39 and 104-118.

The Devonian.—The sea again invaded the land and submerged it wholly. A general period of quiet prevailed during the larger part of the following, the *Devonian Age*. Toward the close of the Mid-Devonian renewed emergence was accompanied by erosion. The era includes the Columbus and Delaware limestones, and the Olentangy and Ohio shales. Where the changes in the relations of land and water were favorable, a rapid intercontinental migration and expansion of life followed, checked only by barriers and by occasional submergence. The record of plants[1] is too imperfect in Ohio for definite discussion, but fossil evidences show that gigantic marine algæ were abundant in the seas, together with fish and ostracoderms, while on the land-islands then exposed there were insects, and mollusks, and on the flat lowland surfaces were broad marshes covered with plants, the larger number of which were herbaceous and highly differentiated. The Devonian plants of contiguous areas show no annual rings to bear evidence of seasonal changes in temperature or intervals of prolonged drought.[2] The flora is far richer than that of the Silurian, and of great botanical interest, since in this period occurred great migrations of plants from the arctic regions, and the development if not the actual beginning of land plants. These facts suggest distinct edapic as well as other environmental changes. The great inland basins contained a vegetation archaic in many features, yet not unlike that now living in swamps and in the tropics. The plants were largely the primitive forerunners of ferns and their allies, and the lower fern-like gymnosperns, with an undergrowth of soft thallose forms, very much like the liverworts of today. Their decay was accelerated by bacterial action.[3]

The Devonian types were in many respects similar to those of the Carboniferous period, and as those of the latter are much better preserved and represented in the Coal flora, a conception of their ecological conditions for growth may be deferred with advantage until the discussion of that period.

A renewed expansion of the sea entrapped the fauna and flora in beds of sediment of great depth. This organic matter is probably the chief source of the oil and gas in use today. It is impossible as yet to state with certainty how these fuels have been formed and concentrated. Chemists suggest an inorganic origin for these products. It is thought, and the theory is supported by laboratory experiments, that the great supplies of petroleum were produced through the agency of iron carbides within the earth, generating the hydrocarbons upon contact with percolating water. But the quantities traceable to such a source

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[1]Newberry, J. S., Devonian plants from Ohio. Jour. Cincinnati Soc. Nat. Hist., Vol. XXII, 1898, p. 48.

[2]White, D., The upper Palæozoic floras, their succession and range; in Willis, B., and Salisbury, R. D., Outlines of geologic history, 1910, pp. 138-160.

[3]Renault, B., Recherches sur les bacteriacees fossiles. Ann. des. sci. nat. bot. VIII series, T. II: 1896, pp. 275-349.

are insignificant in comparison with the great repositories containing the oil. Buried accumulations either of plants, animals or both, can alone account for the origin of gas and oil under the observed conditions. The production of hydrocarbon compounds has been studied in coal mines as the "fire damp," in bogs and swamps as "marsh gas," and in the fermentation of cellulose by anaerobic bacteria. Seaweeds and diatoms are known to contain globules of oil; other oily substances of organic origin are the "cholesterol" found in plants and the fatty parts of animals. The optical phenomena of organic oil, that is, the power of rotating the plane of polarization of light, is not shown by inorganically formed hydrocarbons. In nature, an accumulation of organic debris, the exclusion of air, and the existence of an impervious protecting sedimentary stratum seem to be the essential condition toward rendering the process of distillation and transformation possible. It is often surprising the quantity of oil which an apparently dense rock stratum can hold. Pressure, temperature, viscosity, the nature of surrounding rocks, and a flow of the liquids and gases into porous rocks and cavities, no doubt, must all be taken into account when considering the changes involved in the origin of gas and oil; but at present the organic origin of these fuels seems to have the strongest support.[1]

The Sub-Carboniferous or Mississippian. — The Sub-Carboniferous or Mississippian period which followed the interval of widespread submergence consists of the Bedford shale, Berea grit, the Sunbury shale, the Cuyahoga, Black Hand, and Logan formations, and the Maxville limestone. An increased land area gave increased contact between the atmosphere and the rocks. In the western half of Ohio the period was one largely of sea extension. Disintegration and much erosion must have taken place to give the sedimentay material of the equivalent formations. In many counties, several members of the earlier rock formations occur in isolated masses, but there is no reason to doubt that they once extended over the whole of the State. Their irregular distribution is due to the same erosive agencies which are today at work upon them, and to the action of a system of drainage which, though frequently reversed, coincides in the main with that of today.

A gulf which extended east of the great arch-island enabled plants, as well as animals, to flourish in isolation for a period sufficiently long to differentiate species of its own. For Ohio the record of plant life is poor.[2] But enough fossil vegetation has been recovered in the surrounding states to show that all the leading groups of the Devonian flora were represented with an associated animal life. The different areas exhibit distinct floral and growth-form differences, and suggest either barriers or differences of water content in the soil. The plant

[1]Bownocker, J. A., The occurrence and exploitation of petroleum and natural gas in Ohio, Geol. Surv. Ohio, Bull. 1, 1903.
[2]Ward, L. F., The geological distribution of fossil plants. U. S. Geol. Surv., Washington, D. C., 1889.

associations are varied and of several aspects. The vegetation is remarkably cosmopolitan in distribution, which would premise the absence of climatic zones. Many plants exhibit a striking xeromorphy; the leaves are reduced to linear organs; the stomata have special constructions and are heavily coated and hardened; the stems show development of water storage tissue; the roots are extended horizontally. The general desiccation effects of the habitat resulted, however, not in the extermination of plants favoring free water, but in the limitation of their functional activity to periods of moist or rainy seasons, and in the increase of functional responses. The differentiation has become a factor in distribution and has given the plants a greater range of dispersal; the new place-functions (p. 336) had a survival value in the competitive struggle among the organisms, and in the environmental selection. These phenomena, as will be shown below, are not suggestive of greater severity of climate, but indicate unfavorble conditions in the peaty substratum of the marshes.

The Carboniferous or Pennsylvanian.—The Sub-Carboniferous era was brought to a close by an emergence of considerable areas of shallow lowland, which with their vegetation constitute the great *Carboniferous* or *Pennsylvanian* system and its important Coal measures. The land area of Ohio grew in spite of the fact that it was periodically depressed and degraded. The withdrawal of the sea ultimately resulted in the union of separate land masses and the extension to its present borders. The formations are a series of beds somewhat unlike any heretofore considered. Irregularly distributed through the Carboniferous series are six or eight strata of sandstone, part of them conglomerates, characterized by the presence of quartz pebbles, which sometimes are of large size. This rock is about 100 feet in thickness, generally coarse-grained, and has the coarser quartz pebbles near the base of the formation. The fossils are exclusively casts of plants, and trunks and branches of *Lepidodendron*, *Sigillaria*, and *Calamites*, in some localities heaped up in a confusing mass, like driftwood on a shore at the present day. Newberry ascribes the transportation and deposition of the beds of quartz pebbles to the same cause which has transported the gravels of the later drift, to ice.

Next to them are beds of shale in great variety of colors; they are frequently replaced with sandstone layers or sheets of limestone. The former are frequently cross-bedded, the agents of deposition being rivers or the wind; the latter are all thin, and partly of fresh water origin, and partly of marine origin as is shown by the abundant fossils which they contain. The limestones are in many cases deposits of a calcareous nature, and frequently associated with beds of iron ore or with a layer of clay of varying degree of purity. The clays are frequently overlaid with seams of coal ranging from a mere black line to a dozen feet and more in thickness. Each of these coal seams stands for a former low and undrained land surface, and its vegetation cover. The well marked order of arrangement of the strata underlying the coal seams is intimately connected with a long-continued growth, sudden submergence, and subsequent fossilization of marshes adjacent to an ancient sea, and of great inland xerophytic vegetation formed in island-like masses, very much like the peat bogs of today, but over much wider areas than any single present day bog occupies. The Carboniferous system includes the Pottsville, Allegheny, Conemaugh, Monongahela and Dunkard formations, all of which have been described in great detail in the later volumes of the Geological Survey. Over these rocks, of at least two-thirds of Ohio, are spread in varying thickness, the deposits of the glacial drift. The glacial formations have been very fully described by Leverett;[1] a brief account is given in Chapter V, in connection with the present distribution of vegetation in Ohio lakes and peat deposits, and the physiography of the State.

The mode of arrangement of all geological formations is that of layers resting one upon another, but not usually horizontally. Slow and comparatively gentle movements of the earth's crust, unaccompanied by fractures or displacements have given rise in the State to a system of gentle northeast and southwest foldings. The most important of these is, as has been stated at the outset, the Cincinnati axis, which traverses the State as an arch from Cincinnati to the lake shore, and beyond into Canada. The other lines of elevation are relatively weak, and come into Ohio from Pennsylvania and West Virginia, and are known as the Wellsburg, Cadiz, and Cambridge anticlines, located near places of that name. They are undoubtedly folds of the great series to which the Allegheny mountains of Pennsylvania and West Virginia belong. This emergence of the rocks of the State has its approximate date at the close of the Lower Silurian period, and has never been more than a low mountain chain.

Along a large part of the Cincinnati axis the strata, which once arched over it, have been extensively worn away, and are found resting in regular order on either side. The geological map of Ohio, recently published (see Map, p. 27), shows the areas covered by the principal systems and their series of strata. In the region about Cincinnati the erosion has been greatest, exposing the oldest rocks. The direction of the draining streams of the western half of the State has been mainly determined by this great anticlinal axis. It forms the divide between the waters of the Scioto and the Miami, and between the Sandusky and the Maumee. On the east side of the anticlinal axis, the rocks dip down into a basin in which all the strata form trough-like layers, their edges outcropping eastward on the flanks of the Allegheny Mountains. The older rocks are deeply buried, and the surface is here under-

[1]Leverett, F., Glacial formations and drainage features of the Erie and Ohio basins. U. S. Geological Survey, 1902, Mon. 41.

laid by the highest and most recent of rock formations in Ohio—the Coal measures or ancient vegetation deposits. In the northwestern corner of the State, the strata dip northwest from the anticlinal axis and pass under the Michigan coal basin, precisely as the same series east of the anticline dip beneath the Allegheny coal field, of which Ohio's coal area forms a part.

The Coal Measures and Their Vegetation.—The well marked order of arrangement, which the coal fields of Ohio present, suggest that at the beginning of the Carboniferous age, an arm of a shallow fresh water lake extended inland, and continued in an unbroken sheet up to the Cincinnati arch, which made its western boundary. Year after year, for many centuries an exceedingly dense, luxuriant growth of vegetation covered the surface of the shallow basins as scattered swamps and bog-like marshes, sometimes running into a long connected chain, and sometimes quite isolated. The vegetation was doubtless of many kinds of trees, especially giant ferns and clubmosses, with an undergrowth of shrubs and plants like grasses and sedges. There were many minor differences between the vegetation of different basins; zones of predominating lycopods alternating with ferns. The vegetation must have moved into the open water of protected bays, and inland basins progressively, as groups, distinct in physiognomy and growth-form, the zones varying in width, with the definite conditions of life, and the selective action of the habitat. The plankton association must have been followed by plants nearer the margin and submerged along the gently sloping shore lines. Free floating forms similar to *Azolla*, *Salvinia*, and to various algæ, must have existed in great masses, easily transported by winds and currents, at times completely covering the quiet pools. As their debris formed a slowly rising deposit in the basin, the littoral or shore association must have advanced toward the center of the water basin, forming a mat of interwoven rhizomes and roots, harboring various societies and layers according to the light and water conditions. In time the basin became filled with this debris. In many cases the vegetation accumulated to a depth of more than fifty feet, but this great distance from the mineral substratum or the deficiency of mineral substances never rendered it difficult or impossible for the plants to grow luxuriantly (pp. 386-389). Green plants utilize water and the carbon dioxide of the air to form food, the starches, sugars, fats, and proteins, necessary to their nourishment, and for the successive phases of a normal development. The mineral soil-constituents are not the food of plants; they are indispensable, but their amount is very small in organic substances, and alone they are incapable of sustaining life in plants.

Trees standing erect within a bed of coal, their horizontal roots still embedded in the underlying stratum, the corky bark, the wood, branches, leaves, spores, and fruits of many plants, and even the remains of fossil microörganisms,[1] fungi and mycorhiza, have given their testimony to what once existed. Though not reported in the Coal measures of Ohio, the aggregations, and often large masses of resinous substances, amber, fossil coral, and a multitude of similar substances, by their varying quantities, show the exact character of the vegetation. With the plants were many animals, and where they were most abundant, their fossil remains are found. Little is known of the characteristic plants of the upland vegetation. There are descriptions of about 150 species for Ohio,[2] but most of the interesting fossil plants were found in the roof of Coal No. 1, that is, in the marshes near the base of the Coal measures. In Ohio, this stratigraphical position is "more than two thousand feet above the base of the series, as revealed in the geosynclinal basin of West Virginia, which was first filled with strata of the Coal measures, and long before any similar formations took place upon the ancient marginal Waverly plateau of Ohio."[3]

The flowering plants (*Anthophyta*) had not yet appeared. Bacteria,[4] and other fungi were present, no doubt, in great abundance. Liverworts and mosses (*Bryophyta*) were probably in existence, but they still held an unimportant place. There were principally ferns (*Pteridophyta*), which at this time had reached their greatest development and differentiation. Their first appearance is as strange and distinctive among plants as that of the *Brachiopods* among the animals. They were in part more primitive than now, and in part more advanced, representing transitional types; but they surpassed all other forms in number and persistency. There were scouring rushes (*Calamophyta*) of much higher and more varied organization, and of greater height and diameter than the present forms, and with wide air-spaces in the corticle tissue of the young water roots. The several species of the *Sphenophyllales*, long since extinct, were of tree-like aspect, bearing small wedge-shaped leaves and sporophylls in cones; most of them were found as undergrowth beneath the shade of giant lycopods. The *Equisetales* had hollow jointed stems, with very small narrow leaves; they are mostly extinct plants, of which but one genus, *Equi-*

[1] Renault, B., Recherches sur les bacteriacees fossils. Ann. des. sci. nat. bot. VIII series, T II: 1896, pp. 275-349.

[2] Newberry, J. S., Descriptions of fossil plants. Geol. Surv. Ohio, Palæontology, Vol. I; 1873, pp. 359-385.

Lesquereux, L., Description of the coal flora of the Carboniferous formation in Pennsylvania and throughout the United States. Geol. Surv. Pennsylvania, Vol. II, 1884, pp. 695-977.

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White, D., The upper Palæozoic floras, their succession and range; in Willis, B., and Salisbury, R. D., Outlines of geologic history, 1910, pp. 138-160.

[3] Andrews, E. B., Descriptions of fossil plants from lower Carboniferous strata. Geol. Surv. Ohio, Palaeontology, Vol. II; 1875, pp. 413-426.

[4] Renault, B., Recherches sur les bacteriacees fossiles. Ann. des. sci. nat. bot. VIII series, T II: 1896, p. 276.

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setum, has survived. The *Calamariales*, also long since extinct, grew in dense thickets; they often were of tree-like aspect and dimensions, with narrow distinct leaves, in which the stomata were deeply set. The branches and leaves were placed in whorls on jointed hollow stems which arose from underground rhizoms and increased in diameter by the growth of a cambial zone; their wounds were healed by a development of cork. There were the lycopods (*Lepidophyta*), the largest of the carboniferous plants, in the form of *Lepidodendron* and *Sigillaria*, both with long needle-shaped leaves and stomata in deep furrows on the under side, often protected by a hairy covering. The trees were surface-rooted, the roots spreading out in all directions from the trunk. There were the cycads (*Cycadophyta*), fern-like gymnosperms, related to the modern conifers and flowering plants of which indeed they may have been the ancestors. Of these, the best known are *Cordaites*, *Megalopteris*, *Alethopteris*, and possibly *Lyginopteris*, with its spiny stem and highly dissected xeromophic foliage, *Bennettites*, and perhaps *Ginkgo*. All these were strikingly cosmopolitan in distribution, extending to high latitudes. They were at their climax of vigor and height and verged into more recent types.

How the coal fields were formed hundreds of centuries ago may be seen at any of our lakes today. Our lakes and ponds represent only one of the several conditions under which vegetable matter accumulates. Other, but less important ways, possible to form coal beds are accumulations, (1) built up from the ground by successive elevations of the water table; (2) in sea bottoms beneath "sargasso" vegetation; and (3) in marine swamps, including mangrove swamps and coastal salt marshes. The slight admixture of sediment, which indicates the absence of waves, tidal currents, wind-formed currents and eroding rivers, and the fact that at present only one kind of tree, the mangrove, grows in salt water, is against the view that the coal was formed in salt water or that the charactersitic structure and form of the Coal-measure plants was due to a salt water habitat. No records exist to show that in earlier ages the vegetation of the ocean differed greatly in kind from that now predominating. Ferns and mosses are entirely absent from the ocean; the principal marine vegetation is still formed by algæ, often highly differentiated, which belong to diverse orders. The manner in which the bed of vegetable matter accumulated, and in which it was kept from decay, is a long and interesting chapter. The process has been described in more detail in Chapter VI and in Part III.*

Critical periods suddenly arrived, possibly subsidence accompanied with an invasion of water from an adjacent sea, lake or aggrad-

*The vice-presidential address of Professor Weiss, before the botanical section of the British Association at Portsmouth (Science, N. S., Vol. XXXIV, 1911, pp. 464-480), is of interest in this connection.

ing stream, carrying silt, burying the vegetation under deposits of mud and sand and converting a portion into dry land. The rise in water level brought with it the recurrence of swamp conditions, but the succeeding shallow lake had a narrower area than its predecessor and around its shores and in island-like masses flourished again a dense luxuriant vegetation. In long-continued growth it existed, filling the lake with an accumulation of vegetable debris to the depth and the margin which it still retains as the present coal field. During its formation the drainage relations affected, then as now, the character of the plants predominating in an area, and thus influenced the percentage and kind of ash in the vegetable debris. Frequent local or general disturbances in topography and sedimentation during times of flood brought about the occurrence of partings and seams in coal beds. Not infrequently the vegetation was buried under sheets of limestone that accumulated through precipitation from the invading water. In the subsequent submergence and fossilization there followed other marshes and bog-like swamps. These coal beds represent in some places submerged forests, and in others the coal was probably formed not by the slow growth of vegetation *in situ*, but from drifted vegetable material. But every successive coal-forming area had a narrower lowland basin than its predecessor. This indicates that the changes in the relative level of water were not necessarily accompanied by oscillations in land level.

The geological evidences of the earlier periods of the State's development show that CO_2 existed in much larger quantities than now, since enormous amounts have been fixed in the beds of limestone. The depletion of the CO_2 content, it may be presumed, produced effects on the atmospheric blanket which tended to lower the average temperature and moisture and this, probably, changed the climatic character of the region.[1] Similarly the tremendous amounts of carbon, stored in the basins of the coal measures by the work of green plants, undoubtedly produced a marked effect on the atmospheric content of CO_2. Far-reaching changes in climate must have followed, such as are exemplified in the periodic glaciations of the Pleistocene.

The duration of the Carboniferous period must have been a very long one to yield deposits of coal of such thickness, for it should be remembered that a large part of the vegetable matter has been compressed to a fraction of the original layer of vegetable debris. It is estimated that from 15 to 30 feet of peat are required to make one foot of coal. By a series of changes which are plainly traceable, vegetable matter, peat, lignite, bituminous or soft coal and anthracite, form a series of substances which grade one into another in an unbroken line from complex, organic, partly oxidized compounds at one end to nearly pure carbon at the other. The succession is not necessarily a strictly

[1]Chamberlin, T. C., and Salisbury, R. D., Geology, New York. 1906.

lineal one, since degree of decomposition, chemical changes, previous exposure of the vegetation to reducing action or to oxidation, affect the alterations in various ways (pp. 360-380). The metamorphic changes are hastened where the structural condition of the overlying rock favors the escape of the gaseous products. Ligno-cellulose compounds are the initial substances which gradually lose carbon dioxide marsh gas and water, and so yield the series of products represented by the different kinds of coal. Chemical analysis[1] in which the probable combination of elements is grouped as moisture, volatile hydrocarbons, fixed carbon, ash and sulphur show that the value of coal for fuel is determined mainly by the relative amounts of its volatile hydrocarbons and the fixed carbons. The former represents the free burning constituents of coal and the latter its heating power. Ash and sulphur illustrate the objectionable impurities. Up to a certain point the fuel value or fuel ratio of coal can, therefore, be determined by dividing the fixed carbon percentage by that of the volatile hydrocarbons. A number of different kinds of coal are recognized in the United States whose differentiation depends largely upon these characteristics. But in whatever variety of form, coal is derived from vegetation which grew in lowland, in ponds and lakes in a manner as we find in sub-tropical swamps and in peat bogs of temperate and northern regions today; it was buried under successive layers of matter like itself, and of sediments such as sand and clay; thus protected from atmospheric oxidation and subjected to gradually increasing heat, and the pressure of overlying porous rocks, the vegetation became transformed to the form we now use. The search for coal today is a search for these ancient marshes, bogs and swamp forests hidden under layers of sandstone, shales and drift.[2]

What Conditions Determined Xeromorphy and the Origin of Land Plants.—The characteristic xeromorphy of the carboniferous vegetation has been interpreted by geologists[3] as indicative of a warmer, moister atmosphere, more heavily charged with carbon dioxide than at present. To the writer the facts are hardly consistent with the external conditions assumed. The supposition that xeromorphy involves factors of climate is not necessarily wrong, but calls for a fuller consideration and comparison along with additional factors, the character and magnitude of which is capable of producing like results. A more satisfactory interpretation of the phenomena of xeromorphy would be found in the fact that the present vegetation of undrained swamps and of bogs has many of these xerophytic features, none of which is

[1]Bownocker, J. A., Lord, N. W., Somermeier, E. E., Coal, Geol. Surv. Ohio, Bull. 9, 1908. See also Somermeier, E. E., Coal, McGraw-Hill Co., N. Y., 1912.

[2]Orton, E., The coal fields of Ohio. Geol. Surv. Ohio, Vol. 7, 1893, pp. 255-290. See also subject index of Ohio reports in Bibliography of Ohio Geology; Geol. Surv. Ohio, Bull. 6, 1906.

[3]Chamberlin, T. C., and Salisbury, R. D., Geology, New York, Vol. II, 1906, p. 603.

correlated with atmospheric influences only. The chief cause for both the xeromorphy of the coal flora and the great accumulation of vegetable matter is not to be looked for merely in climatic implications. High temperature and humid air do not necessarily promote, in a high degree, decomposition—the formation of peat has been reported even for regions about the equator[1]—but the great thickness of the deposits suggests rather that the preservation of the debris was favored by a temperate climate and by agents in the soil such as are involved in the accumulation of peat today. Similarly the force of the inference from the xerophytic aspect of the carboniferous vegetation—namely, the peculiarities of leaf size and leaf structure for maintaining a balance between supply and loss of water—gives additional support to the view that the plants encountered adversities of soil-water content rather than of climate. A satisfactory explanation of the phenomenon has been found in the experimental investigations of the writer on the reducing action and toxic character of bog water and bog soil, the results of which are briefly as follows: Poorly drained and undrained water basins and lowlands, whether in areas characterized by limestone formations, by sandstone or glacial drift, become physiologically arid habitats, with the accumulation of vegetable debris. Although water is so abundant in bogs and swamps, yet it is largely unavailable to the plants (Figs. 16-21), on account of various decomposition products, due to the activity of low organisms in the debris-substratum, especially such saprophytes as bacteria and fungi (Figs. 25-26). Peat soils contain bacteria and other fungi in greater number than supposed hitherto, inducing diastatic, inverting, proteolytic, cytohydrolytic and reducing action in the upper layer of the substratum. They vary in kind and number with the nature of the substratum, and show marked interdependence as well as antagonistic action. It has been found that as a general rule, there is an accumulation of injurious substances which must be removed if no deleterious action is to follow, and if complete decomposition of the debris is not to be retarded.

The complex and rather ill-defined "humus acids," more specifically humic, ulmic, crenic, and apocrenic acids, are not the important constituents to which peat owes its antiseptic properties, and which interfere with the action of bacterial organisms. In Ohio peat deposits, at least, the presence of injurious substances in the substratum is not in direct relation to acidity in the soil. Tests on the reducing powers of peat soils show that the wind driven aeration has little effect on the peat substratum beneath the two-foot level. A shallow superficial zone of oxidation exists in peat soils, and the debris below this is sometimes so charged with injurious decomposition products and gases, and so far unaerated as to be inhospitable to all organisms but anaerobic bacteria.

[1]Potonie, H., Die Entstehung der Steinkohle. Berlin, 1910, p. 152.

In the growing season, the temperature of peat soil in the more xerophytic of the succeeding bog associations is not below that of other soils (Table 7). Rapid and passing changes of air temperatures, and the occasional extremes, do not affect the substratum temperatures. Only average effects prevail and the great periodic changes of the dominant climate. The temperatures of the deeper peat strata indicate that there is scarcely anything of a seasonal descent analogous to the circulation or "overturn" in lakes or in ocean.

The continued growth and persistence of the closely related plant associations, and the slow succession of vegetation types in a habitat of that character, is no longer incomprehensible if we remember that the vegetation grows on top of the accumulating debris, and that the water table is always at a high level. The disturbance of the balance produced in the soil is thus not unfavorable to the dominance of the associations. There occur natural successions which are determined, however, not by a deficiency of mineral salts, nor the great distance from the mineral soil, but by an excessive, defective or preventive action in the substratum. The lack of mineral constituents, such as lime, potash and phosphoric acid, does not even render it difficult for mesophytic shrubs and trees to invade and grow as the deposit is built up, and oxidation processes become prominent in the surface layer of the substratum. Acidity, toxicity and reducing action represent merely stages in the decomposition of organic matter. Each plant association augments the efficiency of the soil as a habitat. It cannot be too strongly emphasized that the soil processes exhibit an efficient natural process for the maintenance of productivity relations and that the prime condition determining bog forest successions is not an increase in the mineral constituents in the peat soils (Tables 32-33). To what extent bog plants require the organic compounds arising in peat soils is still undetermined. The assimilation of organic nitrogenous substances is undoubtedly made less difficult on account of the number of saprophytic fungi, endotrophic mycorhiza and tubercles (Table 22), usually present.

The characteristic foliage of bog plants is distinctly an effect of a habitat with a moderate or scanty physiological soil-water content. Extreme xeromorphy is reached in the upper layer of open shrub associations; here the CO_2 percentage of the vertical gradient is least, and approximates that of the free air; the combined effect of the intensity of light and the greater saturation deficiency of the air (Table 9), is provided for by an increased thickness of the mesophyll layer in the foliage to minimize disturbances in the carbon dioxide supply. This, and the narrow leaves with restricted stomata, confined to deep furrows, and in some cases protected by hairs, wax or heavy cuticle, are reaction structures common to plants in bogs where the plants must protect themselves against unfavorable water content in the substratum, and not against unfavorable atmospheric influences. The aerial parts of plants are constantly losing water by transpiration, a process similar to evaporation, but controlled by the plants within certain limits. To reëstablish equilibrium, this water loss is replaced by the supply of water from the substratum by root absorption. The taller plants are thus subjected to a difficulty in maintaining the balance between absorption and transpiration in the same manner as are plants living in deserts or in sandy regions. Though the amount of transpiration exhibited by plants is partly influenced by the physical conditions of the atmosphere, such as temperature, humidity and wind, yet these factors are much more uniform than are the amounts of available water supply. The limitations of this chapter do not permit going into greater detail in respect to the nature and the degree of toxicity in bogs, or in respect to the kinds of plants or the parts of plants which are most affected.

The nearest analogue of the accumulation and the conditions of growth for the vegetation of the Coal measures, are the bogs and marshes of today. Were there no other trustworthy records of the occurrence of bacteria and fungi in Palæozic times,[1] it would still be a natural supposition that these organisms were abundantly represented, and produced physical and chemical changes in the substratum. The transformation products of whatever nature checked the activity of the roots of plants and depressed their transpiration. The striking similarity of the aerial shoots of the carboniferous plants to those of modern times in bogs and undrained swamps, restrain one, therefore, from assuming that the atmosphere differed greatly in temperature and humidity or was different in the chemical constituents from what it is now. There may have been moderate variations in the carbon dioxide content of the air, but this would require experimental proof upon bog plants and the groups of plants similar to those which lived in carboniferous times, the scouring rushes, the lycopods, ferns, cycads and gymnosperms, to assign its limits. The statements in current literature as to the strengths of that gas which green plants can endure are conflicting,[2] and call for further work in the field and in the laboratory.

The consideration of these facts leads to another point—the inevitable conclusion that the form-characters and the fundamental resistance to drought and desiccation distinctive of xerophytic plants whether in bogs or deserts, must have made their appearance within early geologic time. They are not of recent development.[3] The climate of northern America has undergone oscillations between periods of maximum aridity and maximum humidity, with extreme variations

[1]Renault, B., Recherches sur les bacteriacees fossiles. Ann. sci. nat. bot. 8: Vol. II, 1896, pp. 275-349.

[2]Czapek, F., Die Ernährungsphysiologie der Pflanzen seit 1896. Progressus Rei Botanicae Vol. I; 1907, p. 468.

[3]McDougal, D. T., Influence of aridity upon the evolutionary development of plants. The Plant World, Vol. 12; 1909, pp. 217-230.

in temperature during and following the several glacial periods; the amplitude occupying periods of perhaps many thousands of years. Variations in climate so wide apart, indicate an almost complete change in the character of the flora during the geologic periods. The xerophytic features which characterize bogs and deserts are not to be taken, therefore, as having come about by a direct and continuously increasing edaphic or climatic aridity. Aside from the question as to the methods and the dynamic conditions in evolutionary development, it seems certain that the origin of xerophytic forms is not one of recent development in the vegetable kingdom, but must have been concomitant with the diastrophic and gradation processes of the great geologic periods. The great floral evolutions of geologic history were principally one of growth-form, morphological and functional behavior, and not of floral structure alone. Water has always been the most important of all the life relations in the environment of plants. In the early types of gametophytic vegetation it remained necessarily of greatest importance for the movements of gametes in effecting fertilization and for dissemination. The luxurious development of these forms in the ancient areas of low lying land became checked in the stress of aridity encountered with the accumulation of their debris. With the origin and the development of the sporophytic types of vegetation which were, from the first, less dependent upon free water, the prolongation of vegetation activity enabled the plants to occupy the areas with greater habit reactions. The effects of desiccation in the physiologically arid habitats resulted in greater differentiation of organs, in protective and resistance features, and in a greater range of dispersal. The vegetation had now developed to forms capable of occupying dry land and able to maintain themselves as bog or desert vegetation, in localities restricting functional activity. The general movement finally resulted in a land flora of which the mesophytes are the highest expression. The lowland basins and regions of coal formation were undoubtedly those of the evolution of the flora as a whole,[1] and of the several natural vegetation groups which include many diverse associations and societies, in a unity of characteristic physiognomy and growth form. Probably the arctic regions were then the most favorable for the growth and development of xeromorphic plants. Migration from northern centers of dispersal, the periods of climatic aridity and the changes immediately before and after ice invasion, undoubtedly accentuated the ecological evolution of this type of vegetation.

The extensive change in floral types, which is particularly evident through the subordination of the ferns to grasses and heath plants, and the elimination and replacement of the primitive gymnosperms by the later gymnosperms and angiosperms, is largely one of range and variability of protoplasmic forces. In some types the characteristics

[1]Bower, F. O., The origin of a land flora. London, 1908.

often bore no apparent relation to the environment, and were retained under the most varied conditions; yet many other types were profoundly and rapidly modified by changes in climate, physiography and soil processes.

The great development of form in response to the environmental stress was attended by a rapid and luxuriant expansion in range, in successions of vegetation formations, and in sequence of associations. Several forms of cycads, *Bennettites* and conifers now inhabit desert areas. Not less interesting is the fact that many species of heather-plants of Europe, such as *Calluna*, *Empetrum*, several species of pines (*Pinus sylvestris*, *P. montana*), juniper (*Juniperus communis*), birches (*Betula pubescens*, *B. nana*), Labrador tea (*Ledum palustre*), bladderwort (*Utricularia cornuta*), and others, can grow both on extremely dry or warm soil and on extremely cold or wet soils. The observation has repeatedly been made by the writer that in the northern parts of Michigan several species of bog plants leave the peat soils entirely, and are only found upon dry and poor soils. This is notably the case with tamarack (*Larix laricina*), the chokeberries (*Aronia nigra*, *A. arbutifolia*), the blueberries (*Vaccinium corymbosum*, *V. canadense*), the black huckleberry (*Gaylussaccia resinosa*=*bacata*), the shrubby cinquefoil (*Potentilla fruticosa*), sweet gale (*Myrica gale*), the steeple bush (*Spiraea tomentosa*) and several other xerophytes of the peat bogs of Ohio. The cranberries (*Vaccinium* sp.), creeping snowberry (*Chiogenes hispidula*), and wild rosemary (*Andromeda polifolia*) occur in moist ravines and rich woods, while leather leaf (*Chamaedaphne calyculata*), the buck bean (*Menyanthes trifoliata*) and Labrador tea (*Ledum groenlandicum*) are found along slow streams. The majority of these plants occur in Europe and Asia, in habitats of similar conditions. They are bog plants only in the southern part of their range. This departure is in no sense an adaptation to climatic influences only, but is an equilibrium relation or balance between water requirement and the loss of it to the air; between the absorbing organs, the conducting shoots and the transpiration surface against drought conditions common to either habitat. The structures and distribution habits are induced by physiological aridity or poverty of available water. Morphological limitations in the absorption or in the conduction of water do not play a role. The physiological water relation alone must be taken into account for the form and habits of bog and swamp xerophytes, even if the plants inhabit regions of pronounced rainfall and milder temperatures. The appearance of such differentiation can not be taken as one of rapid and notable evolutionary development or as one of the most important in the history of plants; nor would it be safe to assume that bog and desert floras owe their origin to gradual adaptations resulting from the action of climatic changes. The possibilities of survival are very great for forms thrown into the complex conditions of a locality where the functional and structural capacities are suitable for the limiting biochemical factors encountered in the habitat. The plants are functionally fitted to occupy the place in a zone with its system of factors. The qualities of growth which enable competition and the crowding out of other forms are not of primary importance in the struggle and selection where physiological capacities have the survival value for activity during drier seasons. Invaders would not exclude the forms by which a bog or desert is characterized, except where the influence of external conditions has produced irreversible changes in a hereditary line. The structural alterations in roots and shoots of bog plants can not be looked upon as of comparatively recent origin. The phenomenon of xeromorphy has exhibited itself too generally in a variety of plants, and under different conditions in space and time. The transition to xeromorphy has been made not once but several times along different lines of descent. It arose in the highest plants independently from that of the ferns and cycads, and the xeromorphy exhibited here and there among families in a genus probably arose independently along a minor line of development; as such it is the general response in plants to minimize or balance disturbed physiological water relations.

PART III

The Causal and Limiting Factors in the Process of Peat Formation

CHAPTER VIII

CLIMATE AS A CONDITIONING FACTOR IN THE FORMATION OF OHIO PEAT DEPOSITS[1]

General Considerations.—Any one who for the first time sees a peat-depositing lake or pond, almost instinctively marks the striking contrasts which the vegetation of a bog shows when compared with that of an ordinary marsh. It was pointed out in the preceding chapter that the early stages are the same in both cases, but that in later phases of the filling process many plants are especially characteristic of bogs only, such as peat mosses, sundews, pitcher plants, ericads like the cranberry and leather leaf, and of the conifers, notably the tamarack. The agreement in the character of the vegetation with that more commonly noted in the cold temperate regions of the distant north, has invited the attention of many students to the probable causes of this relationship. From time to time, various theories have been advanced as to the environmental conditions favoring the formation of peat deposits, and determining the character of their vegetation. Kihlman[2] regards low temperature and strong drying winds as the prominent factors in northern latitudes. Cold air is much more readily saturated with water vapor than warm air, and hence the relative humidity is constantly high. This condition of low temperature prevents not only excessive transpiration from strong winds, but keeps the accumulation of vegetable matter from complete decomposition. The majority of writers hold this view, for conditions such as Kihlman describes are general in the eastern part of North America, and in that part of the United States east of North Dakota (p. 23). Peat deposits are numerous there, and hence are thought to be correlated with temperate and cold parts of the earth generally. Southward of the fortieth parallel, and west of the nineteenth meridian, the prevalent drying winds, higher temperatures and the lower relative humidity of the air are thought to combine conditions adverse to the growth of bog plants and to

[1]The larger part of this chapter appeared in the Botanical Gazette, Vol. 52, 1911, pp. 127-148.

[2]Kihlman, A. O., Pflanzenbiologische Studien aus Russisch-Lapland. Acta Soc. pro Fauna et Flora fennica, Vol. VI, 1890.

peat formation, since the deposits are fewer or entirely absent.

Früh and Schröter[1] correlate the limiting conditions with low temperature also, but add that the lack of aeration in the soil is the prominent factor determining the relative frequency of occurrence of peat beds and their vegetation cover. Water is considered to be an excellent medium for preserving plant tissue and hence aiding peat formation, since in covering the plant material it excludes air and thus prevents the growth of the organisms which cause decomposition.

More recent peat surveys have revealed the fact that peat deposits occur in Florida, in Brazil, and even as far south as the equator—regions in which low temperatures never occur. Bacteriological (p. 344) and other investigations have shown that water is not wholly a limiting factor in aeration, or in the exclusion of decay organisms from peat deposits. The importance of atmospheric factors must be taken into account in the interpretation of the marked development of xeromorphic structures in plants. But although some of these features may, in part, be correlated with critical conditions of absorption and transpiration, with the gradient of saturation deficiency in the air and the position of transpiring organs, with the seasonal and other changes, there are many characteristics which can not be accounted for in this manner. Atmospheric conditions, relatively uniform as they are over wide areas, can not be said to determine the degree of xeromorphy in bog plants, or the successions of vegetation upon peat deposits.

There is evidently a combination of factors other than that assumed, which makes peat formation possible south, as well as north, and under conditions of unlike topography and climate—factors which have not been discovered or recognized with sufficient clearness. None of the theories advanced can be said to have brought nearer a solution of this phase of the bog and peat problem. The analysis has not included thus far, the recording and accumulating of extensive series of varied and comparative observations, expressed with quantitative exactness. Lesquereux[2] has been among the first to carry on investigations of this nature upon temperature relations. More recent observations have been made by Ganong,[3] Transeau[4] and Cox[5]. The experimental evidence obtained in the field or in the laboratory, and thus far on record, does not, however, cover a period longer than a season; nor the actual range of physical factors such as temperature, evaporation, light-intensity and others. The correlation of these, with investi-

[1]Früh, J., und Schröter, C., Die Moore der Schweiz. Bern, 1904.

[2]Lesquereaux, L., Quelques recherches sur les marais tourbeaux en general. Neuchatel; 1844, p. 277.

[3]Ganong, W. T., Upon raised peat bogs in the province of New Brunswick. Trans. Roy. Soc. of Canada, Vol. III, 1897, pp. 151-154.

[4]Transeau, E. N., The bogs and bog flora of the Huron River Valley. Botanical Gazette, Vol. L, 1905, pp. 419-420.

[5]Cox, J. H., Frost and temperature conditions in the cranberry marshes of Wisconsin. U. S. Dept. of Agri., Weather Bureau Bull. T., 1910.

gations of a similar character carried on in other parts of the country, has not as yet been attempted.

It is obvious, that of the climatic conditions, temperature or evaporation, if sufficiently great in their differences, must have an important bearing on the question of the formation and distribution of peat deposits, and on the structure and growth of the plants in bogs. The conditions under which peat can form and accumulate are those which necessarily limit or favor the growth of plants from which the organic matter is derived. The larger part of the body of bog plants is embedded in the peat at various depths. The several functions take place only within lower and upper critical conditioning factors (p. 307). For instance, the germination of seeds, the absorbing activity of roots and rhizomes, the permeability in protoplasmic membranes and the rate of biochemical action during growth in underground organs must be greatly affected by the actual extreme temperatures encountered, as well as by the rapidity with which changes in temperature occur. Every plant requires for its existence and growth a certain quantity of water. With the aid of light for the early stages of food making, the plants carry on in their green parts that interesting series of chemical processes by which the raw materials consisting of carbon dioxide, water and a small quantity of mineral salts are converted into food such as starch, sugar, protein, and later into living cells, tissues and organs. Each plant has its own peculiar reactions and differs from species of other genera in the necessary minimum quantity of constituents, and in tolerance, to the presence of them in excess. The diurnal and seasonal temperature changes in the peat soil, and the differences in temperature between the aerial and underground portions of plants can not fail to be of equally great importance in the physical and chemical processes, in the reciprocal physiological influences upon which absorption, transpiration, nutrition and transport of solutions from one part of the plant to another depend. The task of securing a coördination between these functions must be indeed a complicated one, varying greatly in different species according to their capacity of tolerance. Optimum conditions are essential in the activity of the soil organisms and in those biochemical changes which are so important to soil productiveness, and which modify plant tissue to peaty material. It is, therefore, clear that conditions as regards efficient temperature, water supply, transpiration and insolation conditions determine greatly the physiognomy of the individual plants, and of the whole vegetation cover in habit of growth and distributional relationships.

Ohio bogs are now only historically connected with the northern region of active peat formation. Their persistence and existence in spite of the climatic changes, of animal and plant migration, invasion, and replacement since the last glacial period, is unique. And the fact also that many peat deposits are reported to occur beyond the margin of the Wisconsin ice sheet, suggests, *a priori*, that the most significant ecological factors are not to be looked for in the continuation of limiting conditions similar to those which prevailed when a colder climate existed than at present. That bog plants are related functionally as well as morphologically, and that they are grouped and localized with reference to more or less definite conditions of their environment, is now a fact no longer questioned. It is also well known that no plant succession or component society is likely to be relatively permanent and stationary, for there are changes constantly taking place in the environment as well as among the dominant plant associations and their secondary units. In a bog, however, but few complicated successions are in evidence, and the treatment of the plant societies from the standpoint of floristic and ecological genetics is, therefore, relatively free from complications. On the other hand, the determination of the factors in bog habitats, and the more detailed study of the dynamics of the process, that is, how some factors are related, their quantity, influence and deviation—this phase of the problem is in a state of uncertainty, and the methods of study have not been satisfactory. When one considers a peat depositing lake or a flat land surface as a habitat, the various causative and limiting conditions entering into the plant environment are not so readily distinguished. The role which temperature plays quantitatively and qualitatively in the formation of peat and in determining the character of the vegetation is in the main not known. What has been said of temperature holds true also for evaporation. The influence of climatic conditions formulated quantitatively is still among the pressing problems of physiological ecology. In connection, therefore, with the analysis of the various physical, chemical and biotic conditions in bog and peat deposits, a discussion of the atmospheric influences as ecological conditions for growth of bog plants and in the formation of peat has been deemed worthy of a closer consideration.

For the past three years field work has been carried on in Ohio especially with the view of testing the reference made by writers as to the part played by low substratum temperature and by the evaporating power of the air. An interpretation of the records and experimental data may seem ill-advised and only in part possible, but until the multiplication of such records is forthcoming there is justification in expressing the conclusions which hold true for local conditions, tentative though they may be. The field work which forms the basis of this chapter was carried on at Buckeye Lake.

Climatic Conditions. — One of the main objects kept in view during the progress of the investigation on the ecology of Buckeye Lake, and one which seemed to the writer an indispensable preface to both the field and the laboratory study, has been the climate of the region (p. 203). The general statistics were taken from *Bulletin Q* of the United States Weather Bureau Service,[1] and from manuscript to which access was had by the courtesy of Section Director Hays of the Columbus (Ohio) Weather Bureau. No continuous series of climatological records have been made on Cranberry Island. The writer made records extending over the period of investigation; these records were supplemented by readings which were taken each time the evaporation of the bog habitat was measured. It is felt that the comparative climate statistics given below are generalized data which do not lend themselves to investigation in physiological ecology. Though facing the same set of climatic factors, few of the species forming the flora of the bog island confront the same physiological problems, and hence any conclusions drawn from mere climatic data, without reference to the varying functional responses of the different species of plants, are certainly inadequate. However, the study of the meteorological observations is suggested mainly in ascertaining the essential differences between the local region and the conditions found in the northern center of bog formation, and in estimating the temperature and humidity exposure of the plants. The data given in table 5 are for Columbus, Ohio; for Ann Arbor, Michigan, where bogs and swamp lands are found more abundantly; and for Marquette, Michigan, where this type of vegetation reaches a still higher development.

TABLE 5

General meteorological conditions

	Columbus, Ohio	Ann Arbor, Mich.	Marquette, Mich.
Elevation	774 ft.	930 ft.	668 ft.
Years of record	31 yrs.	25 yrs.	33 yrs.
Mean seasonal temperature in degrees F.			
Winter	31	26	19
Spring	51	46	37
Summer	73	70	63
Autumn	54	51	45
Annual mean	52	48	41
Absolute maximum	104	101	108
Absolute minimum	−20	−24	−27
Absolute range	124	125	135
Greatest annual range	118		124
Least annual range	89		97
Frost, average date of last in spring	April 16	April 28	May 15
Frost, average date of first in autumn	Oct. 16	Oct. 9	Oct. 2
No. of days in growing season	176	157	140
Mean seasonal precipitation in inches			
Winter	8.9	6.6	6.1
Spring	10	7.9	7.3
Summer	10.3	10.1	9.4
Autumn	8	7.6	9.6
Annual mean	37.2	32.2	32.4
Absolute maximum	51.2	47.7	42.9
Absolute minimum	26.4	21.1	25.3
Mean annual relative humidity	79	79	80
No. days precipitation	144	138	161
Average direction of prevailing wind	S.W.	S.W.	N.W.
Average minimum wind velocity	48 miles		46 miles

[1] Henry, A. J., Climatology of the United States. Bull. Q, U. S. Dept. of Agriculture, Weather Bureau, 1906.

From the data in table 5, it will be observed that the seasonal and annual temperature decreases as one travels from the southern limit toward the northern center of bog vegetation. The climate of the region about Columbus is characterized by a milder winter, but a relatively hot summer. The annual range in temperature is comparatively smaller than at Marquette, 102° F. as against 112° F. The normal annual range is here only between 96° F. (35.5° C.) and −6° F. (−21.11° C.), and the greatest departure from the normal variation does not exceed 16° F. The monthly averages for only two months are at Columbus below 32° F. (0°C.), as against five months for Marquette. The normal number of days per annum with a temperature above 43° F. (6° C.), the factor upon which Schimper[1] and Merriam[2] base the boreal limit, is at Columbus approximately 185, that is, about one-half of the year, as against 122 days at Marquette. The normal sum total of effective daily temperatures above 43° F. (6° C.), the estimate for which is derived by multiplying the mean average monthly minimum temperature of that period by the number of days, is 10414° F. (2520° C.), as against 6466° F. (1422° C.) for Marquette. The normal mean temperature of the six consecutive hottest weeks of the year, effective also in determining the austral limit of species, is 75°. The warmest month is July, with an average monthly maximum of 86°F. (30° C.), as contrasted with 77° F. (25° C.) at Marquette. The coldest months are January and February, with an average monthly minimum of 22° F. and 23° F. (5° and 5.5° C.) respectively, as contrasted with 10° F. and 9° F. (12.5° and 12° C.) respectively for Marquette. The dates of the last killing frost in spring and the earliest in autumn, although not the exact limits of physiological activity in plants, or the limits of the growing period of most plants, are nevertheless an unquestionably important factor. Six months of the year are nominally free from frost about Columbus.

Though the relation between rainfall and the amount of water needed by plants is of great importance in regard to differences in vegetation, the rainfall and its distribution during the seasons, and the number of rainy days, are of greater significance than is the amount of rain. At Columbus precipitation is quite evenly distributed, reaching an optimum of 10.5 inches (26 cm.) during spring and summer, when the vegetative functions of bog plants are more active, with a minimum of 8.5 inches (21 cm.) during the season of low temperature and in the quiescent period of plants. Columbus exceeds the annual precipitation at Marquette by 4.7 inches (11.8 cm.); the average number of days with rainfall during the year, however, is considerably less than in northern Michigan, 144 days as against 161 days. In the north the

[1]Schimper, A. F. W., Pflanzengeographie auf physiologischer Grundlage. Gustav Fischer. Jena, 1898.

[2]Merriam, C. H., Life zones and crop zones of the United States. Division of Biological Survey, U. S. Dept. of Agriculture, Bull. X, 1909, p. 54.

greater precipitation is in the form of snow. Marquette has over five times more snow than Columbus, 125.7 inches (315 cm.), as contrasted with 23.5 inches (59 cm.) here. In this vicinity the longer growing season of the plants has therefore correspondingly more of the precipitation available. On account of the higher temperature more moisture is needed, and hence the evaporation also is much greater here than at Marquette. Cold air does not take up so much water as does hot air; consequently the additional amount of water which the atmosphere is capable of taking up to become saturated, that is, the evaporating power of the air, is greater here than at Marquette. The amount of evaporation also depends upon several other factors and conditions; the values of these will be taken into consideration below. Where evaporation is nearly as great as precipitation, the seasonal distribution of rainfall and humidity is a matter of greatest importance, for it is known that scanty rainfall throughout the year, or relative dryness of air and soil during the growing season, favors the development of xerophytic forms in almost any region. The relative humidity of Columbus and vicinity is only slightly less when compared with the north, the percentage of saturation ranging from 79 to 80 respectively. The distribution varies during the year only to a small extent between the month of least and that of greatest normal humidity.

The rate of movement of air currents is, no doubt, of great importance to vegetation, not only because of the direct mechanical effect and the indirect physiological action in increasing the evaporating power of the air, but also because transpiration increases with the velocity of the wind. That wind is an ecological factor of the greatest importance has been emphasized by many authors. Kihlman and Warming regard xerophytic structures in plants as acquired and necessary, on account of strong drying winds in exposed places. Even humid atmosphere when continually renewed leads to strong transpiration, and the danger may be decreased only as protection is provided either through density and height of species, or admixture of a variety of species in a community of plants. The average maximum velocity of wind does not vary greatly between Columbus and Marquette, and hence the influence of wind, though considerable in more exposed places, has apparently little relation to successions of vegetation or the differences to be accounted for in the character of the local vegetation.

Briefly summarized, the region about Columbus and Buckeye Lake is characterized by a longer growing period with a relatively higher sum total of temperature exposure, a milder winter with normally slight variations, well distributed rainfall, and a relatively high percentage of atmospheric humidity. The local climate is, therefore, preëminently a deciduous forest climate. The whole region was in its recent primitive condition densely forested. On the other hand, the marked increase of bog development in area and in variety of species in northern localities seems to be correlated with a decline in extremes of summer temperatures and an increase in relative humidity. The general effect is to produce a balanced functional relation, though limited in range, between the amounts of water absorbed and transpired. This phenomenon associated with bog habitats will be discussed in connection with a further analysis of the life conditions obtained in bogs from the point of view of their physiological aridity.

If we take the above mentioned climatic factors into account in the interpretation of local bog conditions, it will be seen that meteorological data in this region are not such as to produce or account for xeromorphy or for persistence of bog floras. The climatic changes by which a region varies, if severe and varying between wide diurnal and seasonal changes in temperature, humidity, and light, entail naturally modifications in the functions and in the composition of a flora. The vegetation would be tested to the limits of its power of adjustment and acclimatization, and only the forms which had a greater efficiency of responses and had powers of resistance intensified to a new place function would take up the habitat to the extent in which survival under the modified conditions would be possible. It has been pointed out above that changes in the flora are now occurring and have occurred during the development of the bog island. Many of the former plants are no longer to be found here, while others have survived, have tenaciously held the area under control, and are still constituents of the present flora. Their preservation in this region would seem to be dependent upon less obvious factors than climate. Functional habitat relations, as well as such ecological life relations as are comprised in associations, in ecesis, and succession, need, therefore, more detailed investigation. In determining these the first component to be considered is the role of low substratum temperature. The temperature of a soil is a phytogeographical factor of great significance, but its weightiest importance is in its effect upon the functional activities of roots and rhizomes. Recently the temperature of soils and its fluctuations have received considerable attention. The relationship, however, and the general effect upon plant forms and the correlated functioning are nevertheless but little understood. This circumstance is perhaps the more to be regretted, since, broadly speaking, it seems that the relationship to plant life is the more favorable the more dominating the influence of the physical characters of the soil and particularly the relations prevailing in regard to the physiological water content and efficient temperature.

The Rôle of Substratum Temperature in Bog Habitats.—During the first few months of field work the device chosen for obtaining the substratum temperatures was the "thermophone." The apparatus is based upon the principal that the resistance of an electric conductor changes with its temperature. In obtaining the temperature of peat soils at various depths, the coils were sunk to the required depth, and their leading wires were then connected with the respective binding posts of the indicator box. A buzzing sound in the telephone increases or diminishes according to the position of the pointer while receding from or approaching to a section of the graded dial. Hence the position is soon found where the telephone is silent. This point indicates the temperature of the sunken soil. The instrument is very sensitive, but very inconvenient for obtaining weekly and monthly minimum and maximum temperatures. Later in the season the investigations were planned for a set of thermographs such as MacDougal described,[1] that would make a continuous record of the temperatures at any desired depth. The lack of sufficient funds and the failure to secure similar instruments made it necessary to resort to a conventional though less graphic method of measuring the temperature exposure of plants. In the field work of 1908, 1909, and at present, mercurial minimum and maximum thermometers were therefore used. The thermometers for the deeper peat strata were fastened to wooden poles and pushed down into the soil to the depth of 5 feet (1.5 m.). They remained in the soil during the period of investigation except for such short periods of time as were necessary to make a reading. For strata nearer the surface differential and ordinary mercurial thermometers were used, the bulbs of which were pushed down into the peat around the rhizomes of the plant to a depth of one foot (30 cm.) and three inches (7.5 cm.), respectively. The glass stems of the exposed instruments remained shaded from the direct rays of light. The temperatures recorded below, in centigrade, were generally taken on afternoons, usually between 12 and 2 p. m. It should be kept in mind that the maple-alder zone conditions correspond very nearly to those of the tamarack-willow-poplar zone of the northern bogs and swamps, and that a similar relation exists between the local central zone and the open bog-sedge zone of northern bogs.

[1]MacDougal, D. T., Soil temperatures and vegetation. Monthly Weather Review, U. S. Dept. of Agriculture, Vol. XXXI, 1903, p. 375.

The readings taken during the period of observation are too voluminous for a tabulated record. Only those of the seasons of 1909 will be given in this place (table 6).

TABLE 6

TEMPERATURES (C.) IN THE PEAT SUBSTRATUM OF CRANBERRY ISLAND SEASON OF 1909

Station.	Jan. 12	Feb. 26	Mar. 29	Apr. 23	May 14	June 11	July 17	Aug. 14	Sept. 11	Oct. 2	Nov. 30	Dec. 28
Central (sphagnum-cranberry) zone:												
Air 1.5 m	0.5	5	14	23.5	24	26	24	28	27	17.5	14	3.5
Air 30 cm	0.5	4.5	14	24	25	26	24	28	27	17	14	2.5
Air 7.5 cm	1.0	4.5	14.5	22	26	29	24.5	28	27.5	17	14	2.5
Soil 7.5 cm	0.5	1.5	10	12	14.5	21.5	24	25	22.5	16	7	0.5
Soil 30 cm	0.5	2.0	7	10.5	12	21.0	24	25	22.5	17	8	2.5
Soil 1.5 m	7.5	6.3	8.5	9	11	16.0	21	22	22.5	21.5	16.5	13.0
Maple-alder zone:												
Soil 7.5 cm	0.5	1	11	11	16	20	20.5	22	20	14	8	4
Soil 30 cm	1.5	2.0	9.5	10	14	19.5	21	21.5	20	15.5	9	9.5
Soil 1.5 m	6.5	5.0	8.0	10.5	14	17.5	19.5	21.5	21	19	15.5	14
Lake zone:												
Water 7.5 cm	1.5	1	13.5	14.5	20.5	26	29	28.5	25	15	6.5	3.5
Water 30 cm	1.5	0.5	13.5	14.5	20	26	29	28.5	25	15	6.5	4
Water 1.5 m	1.1	2.7	13	13.8	18.8	22.5	26	26	24	12	6.5	5

A glance at table 6 shows that the temperature conditions, though comparatively uniform and high throughout the bog island, range somewhat lower in the maple-alder zone than in the central zone. There is a large daily as well as annual range in temperature, but the range is considerably less in the soil than in the air above. The data obtained are sufficient to strengthen the observation made, that in the spring the ice in the central zone melts with greater rapidity, and that a higher temperature results from the greater insolation and the increased absorption and retention of heat rays. On days following a sudden lowering of the air temperature, and also on cloudy days, the temperature of the surface bog water and bog soil in the sphagnum-covered area stands above that of the maple-alder zone. This gain in temperature is cumulative and aids in the penetration of heat rays below the surface. The heat supply is obviously the most direct factor contributing to the substratum temperature, for the variations are associated directly with the amount and intensity of sunshine. The extreme slowness in the maple-alder zone is explained partly by the low conductivity of the partially decayed peat and the lack of a free circulation of air above the soil, but largely by the increasing diffusion of light rays due to the leafing out of trees and shrubs.

Another point of interest is the fact that notable differences are found between the temperatures of the bog island and the surrounding lake water. When we compare the effects of gain and loss of heat between the free water surface of the lake and that of the peat area clothed with vegetation, it will be seen that the temperature of the central and the maple-alder zone remains higher than that of the lake during the autumn and winter months, and that during spring and summer the lake water is warmer at the respective (1.5 m.) depths than the peat substratum. Water has a specific heat far greater than any soil; it retains its heat longer and for this reason is warmer than the peat substratum in spring and summer. On the other hand, peat and humus are cooled more rapidly at the surface by the evaporation of water during the warm days of the seasons. The values of both heat conductivity and diffusion are in general lower in peat than in water, and hence a rapid loss of temperature in the peat strata below the surface vegetation is prevented.

A high temperature phenomenon existing in certain places is worthy of special mention. Not infrequently small sheltered areas are found in the central zone bordering the *Rhus-Alnus* thickets where ice never forms in winter. Such temperature conditions would not attract special attention were it not for the fact that usually the temperature is so much lower in the adjacent areas. From a biological standpoint this fact is significant because these conditions favor isolation of habitats and produce a prominent floristic difference. *Wolfiella floridana* commonly occurs in these "warm" pools.

Plants are not dependent so much upon the mean annual temperatures as upon the minima and maxima of temperature encountered, and upon the duration of the vegetation season. To throw some light on the characteristic temperature range occurring throughout the year and within a growing season, the temperature data of the monthly extremes for the seasons of 1908, 1909, and for the autumn and winter of 1907, and the spring of 1910 are appended. As far as the writer is aware, no observations of minima and maxima temperature records within a bog, covering a period of three years, have been carried out thus far. On account of the fact that the present data were obtained at a station whose ecological significance is especially interesting, table 7 of the temperature data is deemed worthy of a closer consideration.

We see again that the temperature of the substrata at the different levels is affected less by the alternate heating and cooling at the surface, but in a far greater degree by the progression of the seasons. It increases slowly during May, is stationary more or less during August and September, and begins to decrease fairly rapidly in November. The maximum temperature occurs in July and August, and the minimum temperature is registered in January for the central zone. That of the maple-alder zone occurs in February. Observations have shown that the lake freezes to a depth of 8-15 inches (20-37 cm.), while the bog is covered by ice to a thickness varying from 3 to 5 inches (7.5-, 12.5 cm.), except for a few places where ice never forms. Consequently the strata in the bog area below the one-foot level (30 cm.), are well protected from lower temperatures and from sudden temperature changes. When the sun's heat melts the ice and snow, the percolating water derived from the melting ice lowers the temperature of the deeper strata a few degrees in the early spring. The wave of temperature increase here falls slightly behind in March, but the upper strata are not prevented from rising in the meanwhile rapidly above the freezing point. Though of ecological importance as a protective cover during the winter months, and of significance as a bad conductor of heat and in decreasing the fluctuations in temperature, the ice and snow do not, therefore, retard appreciably the beginning of favorable growth conditions. The maples and willows of the bog island are in flower about

TABLE 7

MINIMUM AND MAXIMUM TEMPERATURES (C.) IN THE CENTRAL ZONE AT CRANBERRY ISLAND, 1907 TO 1910

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Air:												
Max	18.3	15	25	27.2	31.6	33.3	35	35	34.5	30	23.3	19
Min	- 19.4	- 24.5	- 8.8	- 7.7	0.5	3.3	8.3	7.2	- 1.6	- 5.5	- 9.4	-21.6
Range	37.7	39.5	33.8	34.9	31.1	30.0	26.7	27.8	36.1	35.5	32.7	40.6
Soil:												
1 ft. (0.3 m)												
Max	4.5	3.3	9	13.3	15	25	27	25.5	25	17.7	13	9
Min	0	1.2	0	6.6	10	18	17	21.	16	12.5	8	2.5
Range	4.5	2.1	9	6.7	5	7	10	4.5	9	5.2	5	6.5
Soil:												
5 ft. (1.5 m.)												
Max	13.3	9.2	9	12.2	12.5	17	23	26	22.5	22	20	15.5
Min	7.5	3.9	4	7.2	9.5	14	16	22	20	18	16.5	13
Range	5.8	5.3	5	5	3	3	7	4	2.5	4	3.5	2.5

GREATEST RANGE

Air: max. 35; min. —24.5; range 59.5.
Soil 1 ft. (0.3 m.): max. 27; min. 0; range 27.
Soil 5 ft. (1.5 m.): max. 26; min. 3.9; range 22.1.

8 to 10 days later than those on the campus of the university. A persistence, however, in the peat substratum of the winter cold and ice through the summer months is not proved, at least in this region. The records taken at a depth of 5 feet (1.5 m.) below the surface vegetation show a variation in temperature between 39° and 79° F. (3.9° C.

and 26° C.), i. e., an annual range within 40° F. (22° C.). At this depth only the anærobic bacterial bog flora is most active. The roots and rhizomes of bog plants do not penetrate beyond the depth of 2 feet (0.6 m.), and the roots of maples still less. Plants imbedded in the peat at a depth of 1 foot (0.3 m.) are within ranges of temperature from 32° to 81° F. (0° to 27° C.). The underground growth of the plants continues when the winter temperature in the substratum rises and reaches the gradient from 39° to 47° F. (4° to 8° C.). When these soil temperatures prevail during winter for a sufficient length of time, the different stems and buds shoot upward and develop leaves and lengthen their internodes rapidly in the warmer weather of spring. The absorbing organs at 3 inches (7.5 cm.) depth in the peat substratum encounter a mean average of 54.5° F. (13.5° C.) with an amplitude of more than 86° F. (30° C.). In all cases, however, the range of temperature in the maple-alder zone is less than that of the central zone by a difference of at least 42° F. (6° C.).

These observations and facts disclosed as to the actual temperatures in the peat substratum of Cranberry Island, and the seasonal changes therein point to the following conclusions:

1. The soil temperature of two plant associations formed about the bog island are slightly different, and each association has its own characteristic temperature range.

2. Of the two plant associations in the bog area, the one more liable to extreme low temperatures in the spring and during the growing season is the maple-alder zone along the border of the lake, and not the more xerophytic central zone.

3. The substratum temperatures as phenomena of the local peat deposits are not favorable to the preservation of bog types, if low temperature is considered to be an edaphic criterion; in connection, therefore, with an analysis of the life conditions in this bog area low temperature is not a limiting factor.

4. The persistence of the winter cold and ice through the summer months is a point not proved either by observation or by registering instruments. The persistence of northern forms in this bog, therefore, has some other cause than low temperature of the substratum. In arctic latitudes, no doubt the most significant factor in determining the character and the distribution of plants, as well as in the formation and preservation of humus material, is low temperature. In the latitudes of Ohio, temperature is not a factor in the process. Neither does the accumulation of humus finally bring about edaphic conditions "too cold and too acid."

5. It is not low temperature that kills invading mesophytes, but the edaphic physiological aridity prevailing in the central zone, which decreases the absorption of water by roots at a time when transpiration

and the growth of the plants demand a greater physiological soil-water content.

6. The topographical distribution of plants in the bog is also affected by relations in regard, not to low temperatures, but to the uneven physiological water content and the physical condition in the peat substratum.

The Differences Between Air and Soil Temperatures. — We proceed now to a brief consideration of the question whether the differences between air temperature and that of the soil are sufficiently marked during the growing period to prove a factor in the selection of plants for bog areas. To show this relation, data on the corresponding minimum and maximum air temperatures for the period under investigation have been added to table 7. The records were taken from the Climatological Service of the United States Weather Bureau at Pataskala, some 35 miles (0.56 km.) distant from Buckeye Lake. They represent approximately the conditions at Cranberry Island on the corresponding period. Additional data are found also in table 9. Upon comparison it will be seen that during July and August, the months which proved most critical for the cultivated plants grown in the bog area for experimental purposes, the shoots of plants were in an atmosphere varying between 45° and 95° F. (7° and 35° C.), while the roots and rhizomes were at temperatures varying between 61° and 81° F. (16° and 27° C.), i. e., within a range of temperature differences not less than 16° F. (9° C.). For a growing season lasting from May 5 to October 1, the average date of the latest and earliest killing frost, the actual differences between the temperature of shoots and roots amounted to 62° and 38° F. (34.5° and 21° C.), for each of the absorbing and transpiring organs respectively in the central zone, i. e., within a range of 52° F. (29° C.). It is seen that rapid and passing changes of air temperatures and the occasional extremes do not affect the substratum temperatures. Only average effects prevail and the great periodic seasonal changes. In winter and in summer the minimum temperature of the peat substratum is considerably higher than that of the air. Consequently, the annual mean temperature of the soil greatly exceeds that of the air. The monthly and annual fluctuations of temperature affect the peat area to a depth of 2 m., but they are at no time greater or with a wider range than those of the air. At what depth the mean temperature would remain constant has not been determined.

That the differences between the temperatures of the air and that of the substratum are not as great as is generally supposed, is a fact upon which it is needless to elaborate further. They cannot be looked upon as factors in bog development or in the characteristic xerophily of the sphagnum-covered area in this region, and hence neither the substratum temperature nor the differences between soil and air temperature are of sufficient importance to enter into the problem of bog flora and zonation, or ecesis and succession. The records show that on the basis of temperature as the initial factor the central zone conditions are somewhat more rigorous, and that these conditions are mitigated in the maple-alder zone; but it cannot be claimed that the differences of the plant covering in the two zones are directly correlated with the differences of temperature. With no attempt to minimize its influence, it is evident that for a comparison of habitats, temperature, at least as a single physical factor, is a matter of very subordinate importance on which to establish a casual relation. Those factors acting in conjunction with it demand the greater emphasis. It is questioned, therefore, even for regions where bogs reach their optimum development, whether the coefficient of the differences between the soil and air temperatures is to be looked upon as having a greater value than here in the selection of plants for bog areas, or the production of xeromorphic characters.

Whether or not important correlations between the temperature differences and the transpiratory activities of bog and other plants may be expected, a study of the transpiration quantities will doubtless reveal. Work of this character is now in progress and will be published as soon as opportunity permits.

The Role of the Evaporating Power of Air.—As a preliminary study to the transpiration value of bog plants and to the question also whether the xerophytism and the stunted growth so manifest on maples, poison sumach, and various other plants in the central zone is brought about by an excessive evaporating power of the air, quantitative measurements have been made by the volumetric method to determine the saturation deficiency of the air in three representative stations.

Evaporation is one of the most important factors of the meteorological cycle of a locality. To the student of agriculture and of plant physiology this is a problem the study of which aids in supplying much of the desired information on the growth of plants in irrigated and uncultivated fields. Hann,[1] who studied evaporation chiefly from the point of view of the meteorologist, has pointed out that the amount of water which the atmosphere is capable of taking up to become saturated is one of the indices of the influence of climate. The highly important observations made by Livingston[2], emphasize the fact that the effect of an atmosphere of great evaporating power undoubtedly influences the geographical distribution of plants, and through its local variations exerts an equally determining effect as a physiological and an ecological factor. The problem of evaporation has been but imperfectly appreciated, and though the bibliography of evapo-

[1]Hann, J., Handbook of climatology. 1903.

[2]Livingston, B. E., The relation of desert plants to soil moisture and to evaporation. Carnegie Institution of Washington, Publ. 50. 1906.

———, Evaporation and centers of plant distribution. Plant World, Vol. XI, 1908, pp. 106-112.

ration is extensive,[1] the correlation between the evaporation under different conditions has not been satisfactorily formulated. The evaporating power of the air is generally understood to comprise a resultant of temperature, humidity, and wind. But evaporation is very sensitive to soil as well as to air relations, and since a multitude of local factors may influence either of the two conditions, the amount of evaporation integrates the effect of numerous variables. Evaporation is a rather complex resultant, therefore, and in preparing for an investigation which has in view the measurement of the amount of evaporation in plant societies, it is important to keep in mind the several conditions entering into the problem. It is necessary to recognize that the essential details of the phenomenon of evaporation are different in the great variety of conditions, and require separate and special study appropriate to the peculiar conditions. To measure evaporation in a few places in this locality, and then to assign the results to the region as a whole, is an unreliable procedure. It was intended partially to overcome this difficulty by measuring the variation in evaporation of the vertical as well as the horizontal vapor pressure gradient in a larger number of stations, plotting the results, and drawing isothymes. By a summation of the evaporation, that of the whole area could be calculated with greater accuracy. The distance of Buckeye Lake from Columbus and the inconveniences as to available time have made it difficult to secure the required observations. However, the problem here dealt with does not concern itself with the development of a formulated expression of evaporation for this region. The purpose at present is to obtain quantitative data on the rate of evaporation, and thus to secure direct evidence as to the relation of the observed evaporating power of the air and the nature of the vegetation. The more detailed study of the phenemenon as originally outlined is now in progress.

The ordinary markets are not prepared to supply the well designed standardized self-registering instruments which have been devised to meet the needs of the Weather Bureau.[2] For ecological purposes, an instrument is required which can be placed under conditions practically identical with those which the plants themselves endure. For this purpose a small atmometer partly buried in the soil is desirable. Dr. Forrest Shreve of the Carnegie Desert Laboratory, Tucson, Arizona, courteously left at the disposal of the writer several porous cups of the type as described and used by Livingston.[3] The instruments had been previously standardized with an atmometer at Tuscon, and

[1]Livingston, Mrs. J. G., An annotated bibliography of evaporation. Monthly Weather Review, U. S. Dept. of Agriculture, Vols. 36 and 37. 1908–1909.

[2]Marvin, C. F., Methods and apparatus for the study of evaporation. II. Monthly Weather Review, U. S. Dept. of Agriculture, Vol. 37; 1909, pp. 182-190.

[3]Livingston, B. E., The relation of desert plants to soil moisture and to evaporation. Carnegie Institution of Washington, Publ. 50. 1906.

since they are similar to those sent out from the Desert Laboratory to various other stations in the United States, the readings obtained may be readily compared.

There are certain objections to the porous cups as an instrument in the field study of habitat conditions. The inability of the cup to withstand frost makes it practically impossible to obtain readings for more than the growing period of seven months, and the fact that the instrument does not prevent the direct entrance of rain to the jar introduces an error which becomes very large as the time interval between the reading of the instruments and the length of time and the amount of precipitation increases. The instrument recently described by Yapp[1] and by Livingston eliminates the error last mentioned, but some weighing method, when available, will probably be more exact than any other, since it alone can be employed in the measurement of evaporation from ice, snow, and growing vegetation.

Of the instruments on hand, one was established as a standard in an open lawn freely exposed to the sun and wind on the campus near the University Observatory. It was placed in a manner to obtain readings on the saturation deficiency of the air at a height of 15 cm. above the soil surface. The atmometer remained in the care of Professor H. C. Lord and his assistant Mr. Kendrig, to whom the writer expresses his warmest thanks for their helpful interest. The records were taken three times daily in connection with the climatological observations called for by the United States Weather Bureau Service, and consisted of the reading of the depth of water remaining in a graduated container. The instrument continued in operation from May 21 to September 17, when an accident resulted in the breaking of the graduated retainer. Within a few days the trouble had been remedied and the observations proceeded until October 11, when the first heavy frost occurred.

Another cup was placed in an open and exposed place in the cranberry-sphagnum (central) zone, under conditions similar to those of the standard instrument. It was installed May 14. With the exception of the period from June 11 to July 17, when the total for five weeks was recorded, the loss of water by evaporation was determined at intervals of one week by running in distilled water from a graduate, thus restoring the original water level of the container. Records were obtained until August 21, when it was found that the atmometer had been disturbed. A week later it had disappeared entirely. No attempt was made to replace it by another.

The third instrument stood in the shaded conditions of the maple-alder zone. It was placed near large-sized maples whose cover was relatively dense though open. The reading of this instrument extended uninterruptedly to October 2. During the writer's absence in Europe, the readings in the two plant zones were recorded by Mr.

[1]Yapp, R. H., On stratification in the vegetation of a marsh, and its relations to evaporation and temperature. Annals of Botany, Vol. XXIII, 1909, pp. 275-320.

Dickey; they have since appeared in published form.[1] It is not necessary to reproduce in detail the original observations for the entire period. A series of data from the observations made have been summarized here and the conclusions stated.

Following are the atmometer readings for the several habitats, together with the comparative evaporation expressed in percentage of the standard instrument (table 8).

TABLE 8

ATMOMETER READINGS FOR STATIONS ON CRANBERRY ISLAND AND THE UNIVERSITY CAMPUS

1909 week ending	University station	Central, sphagnum-cranberry zone	Per cent. diff.	Maple-alder zone	Per cent. diff.
May 28	118.8 cc.	97 cc.	81.6	78.1 cc.	65.7
June 4	110.9	92.1	83	60.5	54.5
June 11	88.1	53.3	60.5	27.5	31.2
Five weeks ending July 17	487	349.2	71.7	290.4	59.6
Week ending July 24	151.4	120.2	79.3	77	50
July 31	117.8	69.8	59.2	50.6	42.9
August 7	140.6	69.8	49.6	36.3	25.8
August 14	134.6	82.4	61.2	70.4	52.3
Total evaporation	1349.2	933.8	69.2	690.8	51.2

As was to be expected, by far the smaller part of the total evaporation on Cranberry Island occurred in the maple-alder zone. The annual evaporation within the maple-alder zone is now about three-fourths of that in the open central zone, that is, fully 25 per cent. of the moisture is saved by shade-producing trees and shrubs. The evaporation within this zone is greatest in the season from October to May. The difference in evaporation between this zone and the central zone is then at a minimum, but later it follows closely the growth of the leaves in the early spring and their fall in autumn. The maximum difference occurs in June and July. As the seasons advance, the evaporating power of the air in the forested zone varies with precipitation. Wind and temperature are less effective, for as the leafing out of the trees proceeds, and the increased undergrowth also becomes effective in shade and interference with air currents, the retention of the moisture in the air decreases the evaporation rate and the relative humidity is raised. It would be instructive to follow in more detail the effect of the various meteorological factors on evaporation. This effect can very well be seen if the more important factors like temperature, intensity and duration of light, precipitation, wind, soil, and vegetation are referred to individually. But the results are uncertain and suggest the desirability of preliminary investigations in artificially maintained

[1]Dickey, M. G., Evaporation in a bog habitat. Ohio Naturalist, Vol. X, 1909, pp. 17-23.

conditions by laboratory methods. In a general way, however, the data show that the inner temperatures of the maple-alder zone are lowered and the temperature extremes moderated, but the extremes in summer temperature much more so than those of the winter. The range in temperature is therefore more affected than the absolute temperatures. The importance of shade producers does not consist alone in their effectiveness to reduce transpiration, but also in their inverse influence upon meteorological factors.

The foregoing table also shows that the greater saturation deficiency was recorded for the station on the university campus. The relative evaporation in the three stations is according to the totals 1349.2 cc., 933.8 cc.; and 690.8 cc.; the corresponding ratios are 100, 69.2, and 51.2. These differences for the three stations remained fairly constant throughout. The fact that the evaporation rate for the central zone with its numerous xerophytes should be less than that for an area which supports mesopyhtic forest trees seems anomalous and surprising. Thus for the vegetation on the university campus the furtherance of transpiration by the evaporating power of the air is during some periods approximately two times greater than that on Cranberry Island. This clearly shows that the evaporating power of the air, though furnishing a very valuable criterion for the differentiation between great centers of plant distribution and for the differentiation of habitats, is not an important factor in controlling bog vegetation or determining the character of it. As pointed out elsewhere (p. 242), the relation between succession of vegetation and evaporation shows that the genetically higher associations control evaporation and hence are not determined by it.

With the data on hand, it is not difficult to see that the chief external factor which exerts a direct influence on the evaporation at the bog island is the water area surrounding the island. Evaporation from the water surface and from the vegetation produces a vapor blanket, the action of which influences to a great extent the normal range of evaporation under the varying temperature conditions and consequently the rate of transpiration. The evaporation blanket is readily transported over the open central zone, its rate of movement and consequently the rate of evaporation varying particularly with the action of the wind. In the relatively forested maple-alder zone, however, the vapor blanket is more stationary and hence more uniform in its influence. This vapor blanket covers the locality to a definite height vertically. Studies on the phenomena of evaporation of water over lakes and reservoirs[1] have shown that the vapor pressure of the vertical gradient varies, beginning nearest the evaporating surface with a maximum, and rapidly diminishing within several feet above the evaporating surface, until it approximates to that in the free air. A few isolated

[1]Bigelow, F. H., Studies on the phenomena of the evaporation of water over lakes and reservoirs. Monthly Weather Review, U. S. Dept. of Agriculture, Vol. XXXVI 1908, p. 437.

TABLE 9

Vertical evaporation gradient in the cranberry-sphagnum zone, Cranberry Island

Date	Time	Light*	Anemometer; velocity in miles	Evaporation in cc.: cup at 3 in. (7.5 cm.) above ground	Temperature (C.); absolute,			Evaporation in cc.: cup at 1 ft. (0.3 m.) above ground	Temperature (C.); absolute,			Evaporation in cc.: cup at 5 ft. (1.5 m.) above ground	Temperature; absolute,		
					min.	max.	range		min.	max.	range		min.	max.	range
July 30	6 a. m.	sky clear	34.1	4.86	20	38	18	6.64	20	28	8	9.96	22.5	28	5.5
	12 m.	2 sec.													
	6 p. m		25.1	11.34	21	37	16	14.94	24	32	8	19.92	26.5	29	2.5
July 31	6 a. m.		3.6	0.00	8.5	27	18.5	0.00	8.5	27	18.5	1.66	11	28	17
July 31	12 m.	8–9 sec.	18.1	3.24	16	34	18	6.64	18	30.5	12.5	9.13	17	27	10
July 31	6 p. m.		12.7	6,48	22	42.5	20.5	7.47	21	30.5	9.5	10.37	24.5	28	3.5
Aug. 1	6 a. m.		5.6	0.00	8	22	14	1.66	8	21	13	4.56	10.5	23.5	13
Aug. 1	12 m.	7 sec.	12.1	4.05	15.5	35.5	20	6.64	18.5	32	13.5	7.47	16.5	28	11.5
Aug. 1	6 p. m.		12	8.91	24.5	37	12.5	9.96	23.5	33.5	10	12.45	25.5	31.5	6
Aug. 2	6 a. m.	sky clouded	5.4	0.00	13.5	24.5	11	0.00	13	23.5	10.5	2.49	11	31.5	20.5
Aug. 2	12 m.	28 sec.	23.9	4.81	19	33.5	14.5	7.47	23	31	8	9.96	11	29.5	18.5
Aug. 2	6 p. m.		25.7	5.67	25	34.5	9.5	7.47	24	32	8	10.19	25	30	5
Aug. 3	6 p. m.	cloudy	85.1	14.58	19	37	18	21.58	15	37	22	28.22	17	35	18
Total evaporation				63.94				90.47				126.38			

*Time exposure at noon for sensitive photographic paper to standard tint.

readings confirmed this for the stations in question, as table 9 will show. At first the readings were taken every hour from 6 a. m. to 6 p. m.; later at intervals of six hours. For convenience, the larger time values covering the period from July 30 to August 3 are given here (Fig. 15). The amounts are in the ratios 100, 71, and 50 for positions at 5 feet (1.5 m.), 1 foot (0.3 m.), and 3 inches (7.5 cm.), respectively. Hence in general, the lower stratum of a vegetation has a smaller range in humidity variations and possesses an atmosphere usually much more humid than the upper vegetation stratum or the free air above

Fig. 15.—Experiment station in the cranberry-sphagnum association; in the foreground stunted growth of *Rhus vernix;* photographed July 31, 1910.

the vegetation level. The data confirm the noteworthy results of the evaporation experiments by Yapp,[1] and show that the bog vegetation at the lower levels is exposed to transpiration conditions much less severe than existing at positions above the substratum and those quite clear of vegetation.

But the growth of bog plants and their successful occupation of the habitat do not depend so much upon the total amount of evaporation or the time factor of this exposure, that is, the amount of moisture which the air contains during critical periods of the growing season. The functional activity of the plants is not one of relation to a single factor. In the interrelation of conditions, the real limiting factor to an increase in functional activity is not evaporation or temperature, but the toxicity

[1]Yapp, R. H., On stratification in the vegetation of a marsh, and its relations to evaporation and temperature. Annals of Botany, Vol. 23, 1909, pp. 275-320.

of the substratum. This fact reveals itself only in experimental tests. Toxicity comes markedly into play when the amount of water available for absorption has reached a stationary value, through the activity of the bacterial organisms and other processes. In the field it is very difficult at times to decide which features of the vegetation are to be correlated with low atmospheric humidity and which with variations in temperature and light conditions, or with other factors coöperating at the same time. It is obvious that each in its turn may play the part of a limiting factor, for growth and transpiration are very susceptible to variations in either of these conditions. But in the laboratory the extended experiments with cereals, legumes, and with plants from the various zones of the island have shown that most plants are unable to provide for a balanced relation between the supply of physiological water which the bog substratum can furnish and the excess of water lost during transpiration even when the temperature or the evaporating power of the air are favorable for any length of time. The susceptibility of the plants to the presence of small traces of deleterious bacterial transformation products accumulating in the surface layers of the peat substratum has been demonstrated elsewhere. An intimate and controlling relation has been found to exist between soil bacteria and the plants growing in the central zone. This has shown itself by various physiological and chemical tests, and by the fact that the presence and fitness of bog plants in the central zone is due mainly to more efficient functional responses to physiological drought. The edaphic aridity prevailing in this zone decreases the absorption of water by the roots in wheat plants about 50-65 per cent., at a time when transpiration and the growth of the plants demand a greater physiological water content. The further quotation of definite examples must be postponed. The ratio of the possible rate of water absorption to the rate of transpiration and growth becomes thus the real determining factor in the bog habitat and in the selection and in the distribution of plants. In all cases cultivated agricultural plants become flaccid and the roots appear gelatinous or as if burned black at the tips. The general dwarfing of roots (see illustrations in Chapters IX and X) offers very little efficiency to physiologically arid conditions; nor is the change in form characters of shoot and leaf, induced by the consequent lack of coördination of functions, an advantage or an adaptation. Resistance to desiccation and the capacity for conserving water are more direct and more efficient responses to the limiting condition which the plants meet. This fact is not necessarily to be taken as valid in accounting for all highly specialized and inheritable structures so frequently met with in plants occurring in these habitats. The alteration of shoots and leaves in response to the stimulation of external factors may or may not increase fitness to the conditions, but it is safe to assume that the capacity for physiological changes and responses controls the survival value of plant forms to a greater extent than has been admitted.

CHAPTER IX

THE PHYSIOLOGICAL EFFECTS OF PEAT

General Consideration.—Peat deposits are noted for their dense and luxuriant vegetation. The examples cited in Chapter VI show clearly that peat soils contain apparently all of the constituents required for nutrition, growth and reproduction of a large variety of grasses, shrubs and trees. However, from an agricultural point of view, peat and swamp lands frequently have not given satisfaction, even after drainage or addition of fertilizers. Ample proof of this is seen in the reports of the various experiment stations.[1] Thus far the remedies proposed, as a laboratory experiment, emphasize the fact that although some principles of soil fertility seem well established, and can be applied with definite results, there are yet many complex problems, the solution of which would materially enhance the economic importance of peat and swamp soils. To the writer it has seemed probable for some time, that work upon the chemistry and upon the physiological effects of peat and humus soils must result in data valuable alike to the agriculturalist, the forester and the ecologist.

Early agricultural lore taught that all plants must obtain their food from the external world. It is an opinion which survived from the teaching of Greek philosophers and was regarded as a sound dogma until the chemist Liebig[2] gave a more correct account of plant nutrition. A number of agricultural workers still hold to the ancient dogma, and speak of the soil as plant food in spite of the fact that this once widely accepted theory has been clearly discredited (pp. 380-384). Growth and the proper functioning of roots and shoots depend (1) upon a favorable and adequate water supply to maintain tension (turgor) in the embryonic tissue (meristem), and in the region where the cells enlarge and elongate prior to differentiation, (2) upon a sufficient supply of starch, sugar, protein, and other food materials produced only when the conditions for photosynthesis are fulfilled, (3) upon a good supply of air—oxygen—necessary for ridding the plants and the soil of products of an inevitable decomposition of unstable organic compounds, and (4) upon a suitable temperature. All plants are sensitive to the various external factors. Any one of these conditions may

[1]Hopkins, C. G., and Pettit, J. H., The fertility in Illinois soils. Ill. Agri. Exper. Sta. Bull. 123, 1908, pp. 251-255.

Huston, H. A., and Bryan, A. H., Swamp muck. Rept. Ind. Agri. Exper. Sta., 1900.

Conner, S. D., and Abbott, J. B., Unproductive black soils. Purdue Univ. Agri. Exper. Sta. Bull. 157, 1912.

[2]Sachs, J., Geschichte der Botanik, 1875, p. 481.

vary within wide limits, and any one of them may, therefore, affect the internal (protoplasmic) conditions and retard the general course of development and consequently the form and behavior of the plant. It is extremely difficult to disentangle the complex of forces acting on a plant, but experience is showing that green plants grow normally when supplied solely with water, carbon dioxide and with a very small amount of mineral salts—the constituents of their ash. By judicious treatment it is possible to increase the fertility and the amount of humus in cultivated land in spite of the yearly harvest which removes large quantities of organic substance. Whether of mineral or of organic nature, a soil is not exhausted naturally, for in green plants every organic food substance is directly or indirectly derived from the photosynthetic assimilation of carbon dioxide. Various degrees of dependence exist between all forms of life, but it is ultimately from this source that plants, including both saprophytic and parasitic plants (and animals), derive their food. Plants which are unable to assimilate carbon dioxide must obtain all their food from organic materials in the external world, from vegetable matter such as peat and humus, or from living organisms.

It is not the intention to deny that green plants may absorb any organic substances from without. To a certain extent all plants are able to absorb and assimilate nitrogenous and non-nitrogenous organic compounds, but reliable data on these questions have not as yet been obtained.

The relation of plants to peat and humus soils, the advantageous structures and functions which enable the vegetation to grow and survive in this habitat, the reactions produced, have been of the utmost importance to students of plant physiology. Attempts to nourish green plants with humus solutions were performed by Saussure, Hartig, Johnson, Malagute, Mulder, Unger, Wiegman, Trinchinetti, Detmer, Simon and others,[1] but with varying results. Grandeau[2] obtained data which indicated a slow diosmosis of humus solutions, frequently acting injuriously upon plants. Pfeffer[3] and Godlewski[4] found that seedlings grown in humus, in a receiver containing no carbon dioxide, ceased to develop when the reserve materials of the seed were exhausted. According to Drude[5] a young plant of *Neottia*, surrounded by a small portion of humus gradually became starved as development continued. Transeau[6] and Livingston[7] obtained widely different plant forms of

[1]Pfeffer, W., Physiology of Plants, Oxford, Vol. I, 1900, p. 368.

[2]Grandeau, L., Recherches sur le role des matières organiques dans les phenomenes de la nutrition des plants. Nancy, 1872.

[3]Pfeffer, W., Monatsberichte d. Berl. Akad., 1873, p. 784.

[4]Godlewski, E., Botanische Zeitung, 1879, p. 88.

[5]Drude, O., Biologie von Monotropa, 1873, p. 26.

[6]Transeau, E. N., The development of palisade tissue and resinous deposits in leaves. Science, N. S., Vol. XIX, 1904, pp. 866-867; also Bot. Gazette, Vol. XLI, 1906, p. 38.

[7]Livingston, B. E., Physiological properties of bog water. Bot. Gaz., Vol. XXXIX, 1905, pp. 348-355.

Rumex and *Stigeoclonium* respectively, as a growth-response to water from peat bogs.

The results obtained have received various interpretations. Schimper,[1] and with him Warming,[2] look upon the presence of free humus acids as the weightiest cause and regard peaty soils and bog habitats as being physiologically dry. Volkens,[3] Davis[4] and Burns[5] conclude that physical drought, due to the lowering of the soil water table during summer and the consequent drying of the superficial layers of peat, induces the xeromorphy of bog plants, while Crump[6] suggests the great water-retaining power of peat. Kihlman,[7] Goebel[8] and Yapp[9] emphasize the importance of atmospheric factors, especially drying winds and deficiency in air-humidity when accompanied by coldness of soil. Transeau, following Früh and Schröter, correlates the condition with low soil temperature, and the paucity of oxygen in the soil, while Livingston suggests the presence of chemical substances not in direct relation to the acidity of the soil.

The Harmful Organic Constituents of Peat Soils in Relation to Plant Activity.—To determine the presence and possible nature of the injurious substances in peat affecting plants through their toxic effects, the following experiments were planned with bog water from Buckeye Lake. The water and bog soil used in the experiments were brought every month to the laboratory in glazed earthenware jugs from stations which remained identical throughout the period of investigation. The chemical and bacteriological analyses are given in the following chapters.

Familiarity with the behavior and the conditions of development of *Marchantia polymorpha*[10] suggested marchantia gemmae of known history as an indicator for preliminary observations. A large number of gemmae were placed in crystallizing dishes (9.5×4^{cm}) containing 100^{cc} of bog water. Cultures were prepared, containing respectively the untreated bog water from each zone and spring water. The gemmae were allowed to float on the surface of the solutions. An additional series of test conditions was arranged at the same time from the bog water of each zone variously treated. In the table given below, culture medium No. 3 is bog water aerated daily by means of a rubber bulb;

[1]Schimper, A. F. W., Pflanzengeographie auf physiologischer Grundlage. Jena. 1898, p. 4.

[2]Warming, E., Oecology of plants. Oxford, 1909, p. 195.

[3]Volkens, G., Zur Kenntnis der Beziehungen zwischen Standort und anatomaischen Bau der Vegetationsorgane. Jahrb. d. bot.Museums zu Berlin. Bd III, 1884, p. 24.

[4]Davis, C. A., Ecology of Peat formation in Michigan. State Geol. Surv., 1906, p. 160.

[5]Burns, G. P., Edaphic conditions in Peat bogs of southern Michigan. Bot. Gaz., Vol. LII, 1911, p. 119.

[6]Crump, W. B., The wilting of moorland plants. Rept. Brit. Assoc., 1911–12.

[7]Kihlman, loc. cit., p. 285.

[8]Goebel, K., Pflanzenbiologische Schilderungen. Teil. II, 1891, p. 11.

[9]Yapp, loc. cit., p. 301.

[10]Dachnowski, A., Zur Kenntnis der Entwicklungs-Physiologie von *Marchantia polymorpha.* Jahrb. Wiss. Bot., Vol. XLIV, 1907, pp. 251-286.

No. 4 is prepared by mixing with the bog water dry calcium carbonate and then filtering off the solution; No. 5 is treated by shaking the bog water with carbon (lampblack) and then filtering off the solution; No. 6 is a culture medium obtained by growing in distilled water in battery jars a set of representative plants from each zone. The attempt is made here to simulate undrained bog conditions and to test the water for excretions of roots. To discover whether the effects of poisons were also manifest in the bog substratum, a relatively concentrated aqueous extract was prepared. Quantities of the subsoil from each station were taken from a layer 30^{cm} below the surface vegetation and dried in an oven at a temperature varying between 126° and 140° F. (52° and 60° C.). One gram of the material was then mixed with 100^{cc} of distilled water and left standing for several days The soil solution thus obtained was used as culture medium No. 1. There were thus produced six conditions for each zone in which it was possible to test the bog soils, the excretions of bog plants, the effect of aeration, and the toxic ingredients of bog water The following table 10, shows the results of growth in length of marchantia gemmae during periods of twelve and twenty-five days.

It will be noticed that the gemmae made scarcely any growth in the bog soil solution, while in the untreated bog water a fairly good growth occurred. An inhibiting action of these solutions is plainly marked. Evidence of this is further obtained from a microscopic study. For the first five or six days the gemmae made some growth, but after

TABLE 10

MARCHANTIA POLYMORPHA

Culture solution	Growth in 12 days Length in mm.	Growth in 25 days Length in mm.	Remarks
I. Central zone:			
1. Bog soil extract	1 and less	....	dead after 8 days
2. Bog water untreated	1 -1.5	1.5- 2	filamentous outgrowths
3. Bog water aerated	4 -6	6 - 8	
4. Bog water neutral	5 -5.5	6 - 7.5	
5. Bog water filtered	7.5-8	11 -12	
6. Bog plant water	2	5	
7. Spring water	3 -4	4 - 5	
II. Maple-alder zone:			
1. Bog soil extract	1	1 - 2	larger number dead after 12 days
2. Bog water untreated	6 -7.5	11	
3. Bog water aerated	6 -8	12	
4. Bog water neutral	6	10.5-14	
5. Bog water filtered	5 -8	10 -11	
6. Bog plant water	5 -6	10 -12	

ten days development ceased. Only in the untreated bog water the two opposite growing points of the gemmae were thrifty in appearance. They gradually gave rise to narrow thread-like filaments, which at the end of the twentieth day began to broaden at the tip. In all solutions growth was greatly increased after treatment. Exceptions were noted only when the bog water used was collected just following a period of heavy rains, or when the vessels containing the bog water were left

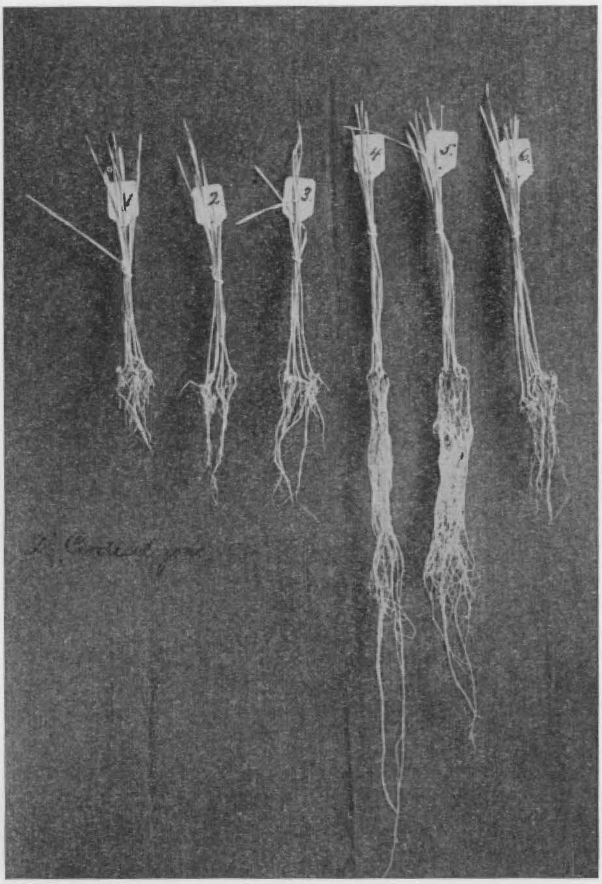

Fig. 16.—Wheat plants from various cultures of bog water and bog soil. Numbers as in the text, p. 313. Six plants from each solution.

uncorked. The differences in growth in the various solutions were less marked, showing that the degree of toxicity at one concentration was entirely different at another. The same is to be said of solution No. 6; its toxic character became more marked with increase in the time during which the bog plants were under cultivation.

Briefly summarized, the data thus far agree in showing (1) that the contrasts in the relative growth of plants in solutions from the maple-alder zone were less marked than those in the solutions from the central zone; (2) that the inhibiting factors of bog conditions are in part due to the presence of injurious water-soluble substances; (3) that the central zone possesses these toxic substances more decidedly than the maple-alder zone; and (4) that in both the toxicity can be corrected by a method of aeration and by the use of calcium carbonate and carbon black.

A series of experiments was next made in the form of bog water

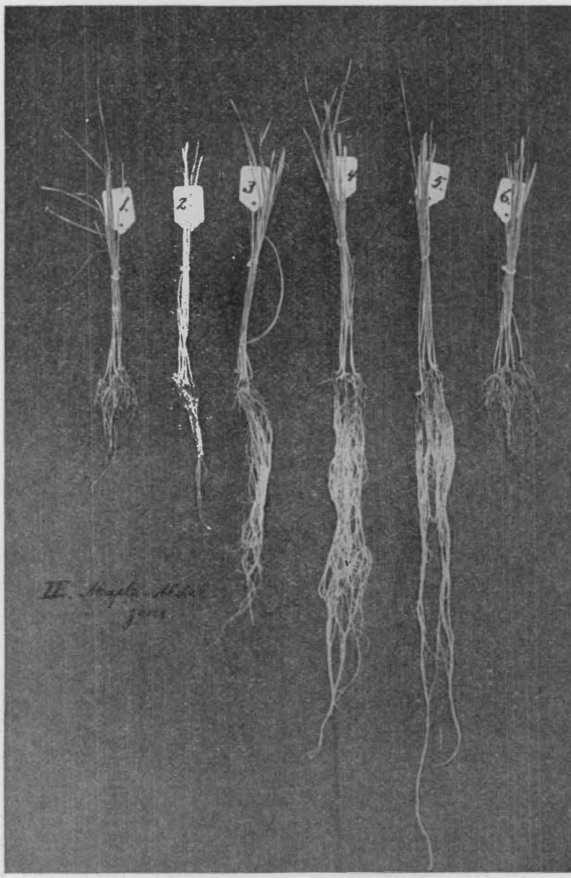

Fig. 17.—Wheat plants from various cultures of bog water and bog soil. Numbers as in the text, p. 313. Six plants from each solution.

cultures with various cultivated plants. Half-liter glass jars of the Mason pattern were used, and prepared in the conventional way. The seeds were germinated in sawdust; later germination in quartz sand and in paraffin-coated disks of galvanized iron wire was found more satisfactory. Transplanting was done when the plants had attained a height of 5-6^{cm}. The culture media used were prepared as indicated for marchantia. From two to six plants were used for 400^{cc} of solution.

Each experiment was continued for 7 to 10 days according to the amount of water transpired, before renewing the culture solution. The different cultures always stood side by side in the university greenhouse, so as to give uniform environment. The light conditions were the same also; direct sunlight was avoided by cloth screens. In place of temperature and moisture readings, measurements of the evaporation power of the air were obtained from the records of two atmometers. The instruments were prepared on a scale as given by Livingston.[1] The integration of humidity, temperature, and air-current data given in a weekly rate varied betwwen 200 and 270^{cc}.

As an aid for comparing the rate of growth of similar plants in different media various criteria were used. The main emphasis, however, is placed upon the total transpiration for a definite period of growth, since the difference between the amounts of water lost has been shown

TABLE 11

PERCENTAGE INCREASE IN TRANSPIRATION

Culture solution.	Wheat.	Corn.	Phaseolus.	Vicia faba.	Elm.	Buckeye.	Cowpea.	Oats.	Tradescantia.
I. Central zone:									
1. Bog soil extract*	0	0	0	0	0	---	---	---	0
2. Bog water untreated	19	16	113	22	68	0	0	---	9.8
3. Bog water aerated	55	27	201	---	---	1.3	20	---	---
4. Bog water neutral	209	91	---	100	---	---	---	---	8.6
5. Bog water filtered	245	52	225	215	94	38.8	42	---	24.7
6. Bog plant water	54	22	184	---	---	---	---	---	---
II. Maple-alder zone:									
1. Bog soil extract*	0	0	0	---	---	---	---	0	---
2. Bog water untreated	38	65	287	---	---	---	---	90	---
3. Bog water aerated	164	71	---	---	---	---	---	44	---
4. Bog water neutral	298	136	335	---	---	---	---	148	---
5. Bog water filtered	256	76	---	---	---	---	---	---	---
6. Bog plant water	11	40	178	---	---	---	---	113	---

*4^{gm} of bog soil and 400^{cc} distilled water.

to be equivalent to the difference between the physiological value of the solutions.[2] Other criteria employed were the condition of the roots, green and dry weight of plants, length and anatomical structure of roots, stem, and leaves. None of these alone can be regarded as accurate measures of plant activity, but taken together they generally agree in indicating the relative value of the results. Without dwelling here at length upon the exact data derived from these experiments, only the

[1]Livingston, B. E., The relation of desert plants to soil moisture and to evaporation. Carnegie Inst. of Washington, Publication 50, 1906, p. 20.

[2]Whitney, M., and Cameron, F. K., The chemistry of the soil as related to crop production. U. S. Department of Agriculture, Bureau of Soils. Bull. 23, 1903.

results in transpiration-increase are given below in tabular form. The percentage increase in transpiration is calculated for the larger number of the plants upon the basis of the quantities for the bog soil solution considering it as unity.

An increase in the dry weight of roots and tops was obtained in all plants growing in the solutions treated with $CaCO_3$ and carbon black. For the corn and wheat respectively the increase in the dry matter

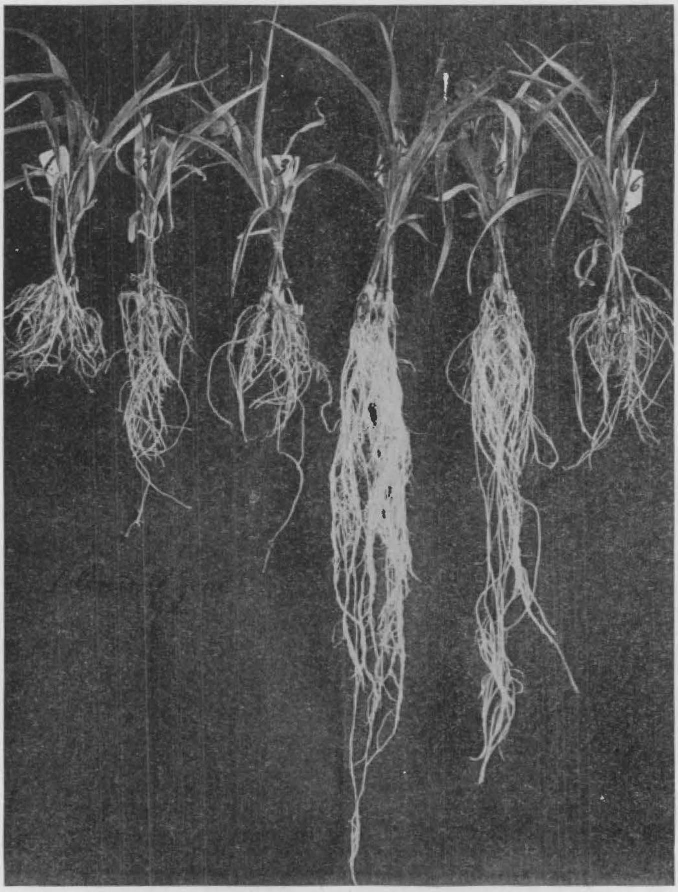

Fig. 18.—Corn plants from the various cultures of bog water and bog soil. Numbers as in the text, p. 313. Four plants from each solution.

produced varied from 20 per cent. to 50 per cent. during the time of the experiment.

It will be observed that the evidence derived from wheat, corn, bean, elm, and buckeye seedlings (two years old), and other plants, yields results and conclusions similar to those pointed out for marchantia. The plants grown in the bog soil extract and in the untreated bog water show stunting clearly in the roots. The tops of the plants are more nearly alike, except in the stronger solutions. Marked differences in the degree of sensitiveness to toxicity or of the oxidizing power[1] of roots are noticeable for the various plants. *Phaseolus* and *Vicia faba* proved thus far to be the most plastic plants. In the solutions filtered with $CaCO_3$ and carbon black the tops surpass in development

Fig. 19.—Corn plants from the various cultures of bog water and bog soil. Numbers as in the text, p. 313. Four plates from each solution.

the growth of roots. The plants show marked variations in the internal structure of leaf and stem. Those grown in the bog soil extracts show distinct xeromorphic characters. The leaves are reduced in area, thicker, of a deeper green, and with revolute margins; responses which

[1]Molisch, K., Sitzungsber. Akd. Wiss., Wien., Vol. XCVI, 1887, p. 84.
See also Schreiner, O., and Reed, H. S., Bot. Gaz., Vol. XLVII, 1909, pp. 355-388.

cannot be attributed to light but to a reduced transpiration current,[1] consequent, however, upon the toxicity of the habitat (Figs. 16-21).

It is worthy of note in this connection that when grown in a 0.01 per cent. solution of strychnine sulfate, atropine sulfate, or other toxic compound of a similar nature and with a high reducing power, the same dwarfing effects are obtained with *Phaseolus*. When treated with $CaCO_3$ and carbon black the solutions become highly beneficial. The accelerated growth and transpiration are no doubt due to the presence of these substances in small amounts, and the behavior of the plants is very much like those grown in a 0.0001 per cent. solution of strychnine or atropine sulfate.

The striking agreement of results obtained from such a variety of

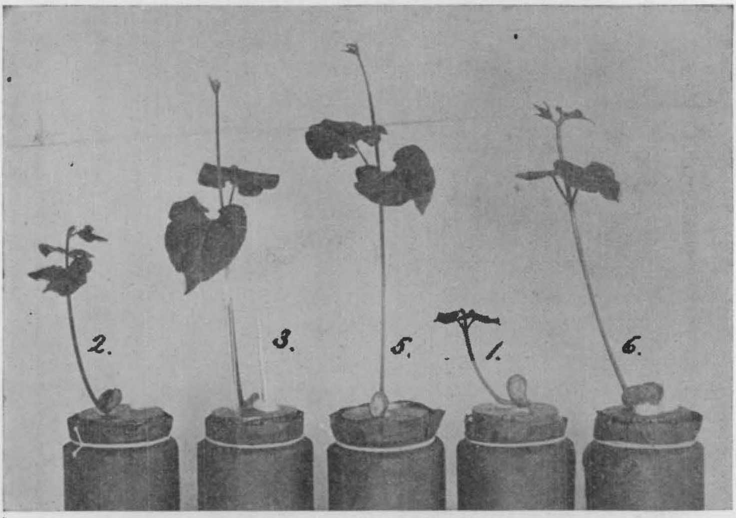

Fig. 20.—Average plants of *Phaseolus multiflorus*, showing effect of bog water variously treated. Numbers as in the text, p. 313.

material seems sufficient proof that the factors inhibiting plant growth and plant association and successsion are at least in part due to the plants themselves. Carbon black and calcium carbonate add no soluble matter to the solutions,[2] hence it becomes certain that the beneficial effects cannot be due to the introduction of nutrient material but to the taking up, i. e., the adsorption of injurious substances present.[3]

[1]Transeau, E. N., The development of palisade tissue and resinous deposits in eaves. Science, N. S., Vol. XIX, 1904, p. 866.

Vesque, J., et Viet, Ch. De l'influence sur la structure anatomique des vegetaux. Ann. Sci. Bot. VI, Vol. XII, 1881, pp. 167, 176.

Kohl, G., Die Transpiration der Pflanzen und ihre Einwirkung auf die Ausbildung pflanslicher Gewebe. Braunschweig, 1886, pp. 95-103.

[2]Brezeale, J. F., Effect of certain solids upon the growth of seedlings in water cultures. Bot. Gazette, Vol. XLI, 1906, p. 54.

[3]Michaelis, L., Dynamik der Oberflächen. Dresden, 1909.

This would indicate, therefore, that the changes in the soil conditions are produced by noxious substances formed in the absence of O_2. They may be products of decomposition, perhaps they are in part plant excreta, but whatever their nature, they are water-soluble toxic substances which retard oxidation in the tissues and decrease transpiration, thus causing xeromorphy, stunting and even death.

It may be readily questioned whether part of the response arises

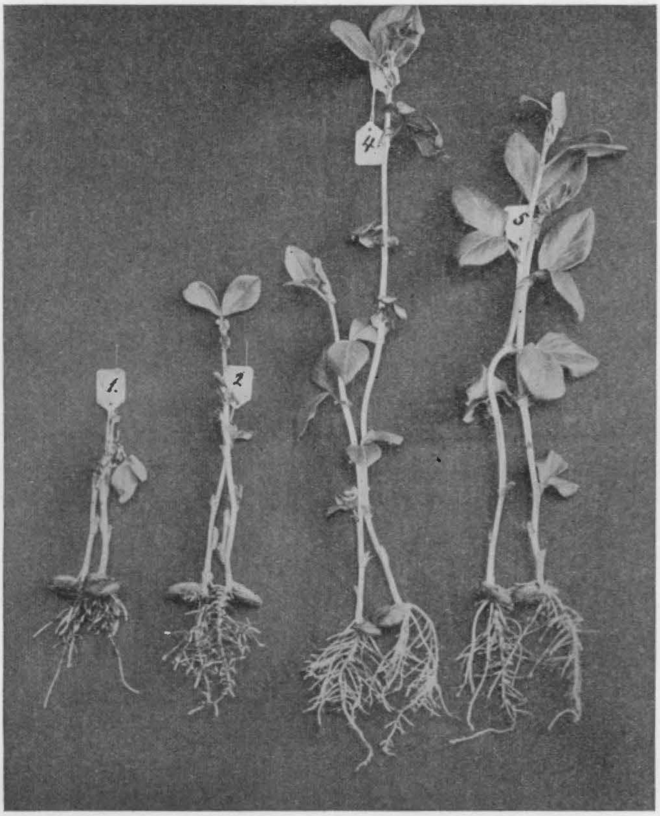

Fig. 21.—*Vicia faba* from cultures of the central zone. Numbers as in text, p. 313. Transpiration data and photograph by Miss Freda Detmers.

from a deficiency of oxygen in the soil. The evidence obtained by Bennett[1] is against aerotropism in roots. It follows, therefore, that results reported as due to lack of aeration in the bog substratum are really due to toxicity. Under natural conditions the inhibiting effect is eliminated by aeration, a slow process of oxidation preventing the accumulation of injurious substances in the soil. However, on account of the great demand for oxygen, the process can be carried on efficiently only near the surface. Beneath, the active substances are more plentiful

[1]Bennett, M. E., Are roots aerotropic? Bot. Gazette, Vol. XXXVII, 1904, p. 241.

in the dead material. An undrained peat substratum, therefore, must necessarily cause more marked deterioration in development and permit a different association and succession of plants than a drained habitat.

Peat Toxins and Their Effect Upon Tree Growth.—In all temperate zones, at least, trees form annually one layer of wood, which appears on a cross-section of a tree as a ring, more or less clearly defined. The rate at which the diameter and the area of any cross-section of the tree increases, can therefore be easily ascertained by measuring the width of the rings. To obtain direct evidence as to the relation of the rate of wood formation to the nature of the habitat, and to obtain information on the value of a biometric study in differentiating such habitats, statistical work has been carried on during the winter of 1907-8. The purpose of the following is to call attention to the fact that statistical methods first used by Galton and now applied by Davenport,[1] Pearson,[2] Shull,[3] and others to the more complicated questions in variation and heredity, may be of service also in Forestry problems as well as in questions of Ecology.

The northern shore near the bog-island at Buckeye Lake supports at various places a forest vegetation in the form of woodlots. The most common trees are the beech, elm, maple, oak, chestnut and walnut—examples of a temporary mesophytic forest association. In determining the influence on annual accretion of wood the stumps of red maple were selected A number of these trees had been just recently felled both in the bog and on the shores nearby. It seemed desirable therefore to procure and record data on measurements from such trees of the two conditions of habitat, as were nearly the same in size, age, uniformly concentric growth of wood, and general environment. The general climate is assumed to be almost identical for both places, and being thus eliminated, it became easier to determine the effect of soil conditions upon the rate of diameter growth of the species.

From the number of trees at disposal, five were selected from the marginal bog zone, and three were chosen from the woodlots near the shore. It may be objected that not enough trees were analyzed to permit the conclusion drawn. In order to eliminate sources of error, measurements were made, indeed, on a larger number of sample trees. To the writer, however, it seemed that the degree of confidence and the accuracy of the statistical result depended not so much upon numbers, as upon the functional criteria of the environment. It was not so much the object of this study to establish variability, as to find a suitable method of determining the influence of various factors in the environ-

[1]Davenport, C. B., Statistical methods with special reference to biological variation. New York. J. Wiley & Sons, 1899; and Revised edition, 1904.

[2]Pearson, K., Grammar of Science. 1900.

——————, On the sources of apparent polymorphism in plants, etc. Biometrika, 1902, I, pp. 304-306.

[3]Shull, G. H., Place constants for Aster prenanthoides. Bot. Gazette, 1904, Vol. XXXVIII, pp. 333-375.

ment. A method was sought by which temperature, light, humidity and soil data could be combined in a single number. The fact that so large a part of plant activities and adaptation is directly or indirectly connected with climatic and edaphic factors, suggested that if a comparative and statistical study of secondary growth on similar trees of various pronounced habitats were made, a new basis for determining climatic and edaphic regions of optimum development would be at hand.

Put in tabular form the results of the measurements are as follows:

Width of rings in mm	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Frequencies in bog-habitat	16	10	23	20	27	12	20	5	7	5
Frequencies in woodlots	26	30	31	9	6	---	---	---	---	---
Width of rings in mm	---	6	6.5	7	7.5	8	8.5	9	9.5	10
Frequencies in bog habitat	---	5	5	6	1	2	0	1	0	2
Frequencies in woodlots	---	---	---	---	---	---	---	---	---	---

These frequency distributions are shown graphically in Fig. 22. The abscissas give width in millimeters, the ordinates frequencies of rings. The variation constants deduced from them are indicated on page 321.

For the benefit of those unfamiliar with the biometric method of study employed here, a brief discusssion of the more salient points is appended. For a more complete statement the reader is referred to

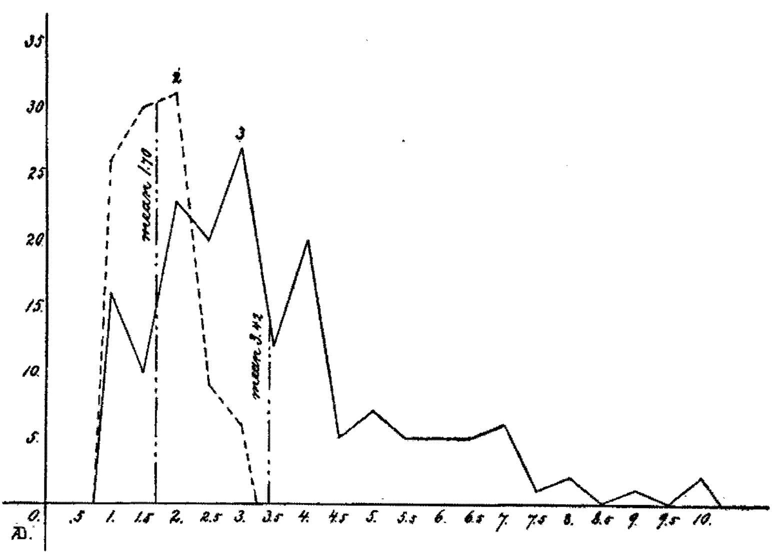

Fig. 22.—Frequency curves showing variation in width of the annual wood-increment in *Acer rubrum*. Continuous lines—bog habitat; Dotted lines—woodlot habitat.

Davenport's "Statistical Methods"[1] or the more popular work of Pearson.[2]

It will be noted that in the trees of the bog habitat, there are more rings three mm. long than of any other length, while in the second type of habitat the greater number of rings has shown two mm. This highest frequency or most common length is known as the mode. It shows clearly the prevailing *type* of wood-accretion. The distribution decreases in both directions from the mode, but least so in the woodlot habitat. The practical importance of the information afforded by this value is apparent. We have here the average prevailing state or place-habit of a similar lot of individuals from two distinct places. It is a characteristic which has been determined by influences covering a period of time (the age of the trees) long enough to eliminate the effect of incidental fluctuations in the habitat. In selecting one character for measurement it must not be forgotten, of course, that the organism is a correlated unit or whole. Change of environment may alter, therefore, a great variety of characters. Whatever the species, its differences constitute a distribution of deviations extending sometimes through a considerable range. Points such as these the systematist, above all, must necessarily consider.

Another conception of the character and the amount of wood-accretion and its distribution is possible through the arithmetical average or mean. Multiplying the value of each variate by its frequency, adding the results and dividing the sum by the total number of rings, we thus get a determination of the mean or average length. In this case the mean length is 3.42 mm. and 1.70 mm. respectively for each of the habitats under consideration. These values differ very sensibly from the most common length or mode. It will be seen at once that the deviations in excess of the mode are in the case of the bog habitat larger and in the woodlots smaller. The mean is in the latter case less and in the former greater than the respective mode. Such distributions are termed skew—the mode and the mean are separated from each other by a certain measurable distance. The relative breadth of the curves exhibits to the eye the great variability and the prominent skewness.

There have been various interpretations of skewness, but it is evident that we are dealing here with the results of direct physiological reactions to the changes in the environment. On an average the annual accretion in woodlot conditions is by far less than in the bog habitat. Not all individual trees are alike sensitive to changed conditions, but the greater value of the positive skewness in the bog habitat indicates that only a small proportion of the variates is conservative. It is

[1]Davenport, C. B., Statistical methods with special reference to biological variation. New York. J. Wiley & Sons, 1899; and Revised edition, 1904.

[2]Pearson, K., Grammar of Science. 1911.

plain, therefore, that the position of the mode and the negative skewness in the woodlot forms has resulted from physiological variation, i. e., from the prevailing edaphic conditions of that place, and that the differences in the environment have changed the type, the variability and even the sign of the skewness.

The frequency curves enable us to perceive still another relation. It will be observed that some of the rings deviate but little from the mode or the mean, while others deviate more and some even very much. For instance, the deviations from the mean in the frequencies of the woodlot samples are −.70, −.20, +.30, +.80, and +1.30 The average deviation is omitted here as having no particular significance. Usually a standard deviation is derived in the following manner. The deviation of each frequency from the mean is squared and then multiplied by its corresponding frequency; the products are added and then divided by the total number of variates, and the square root extracted. The result as corrected by a number representing the probable error is the standard deviation. We thus arrive at a value 1.87 mm. for the bog habitat, and 0.56 mm. for the woodlot habitat, which stands as a definite measure of variability. It enables comparisons from year to year and between different localities, advantages which are too obvious to require elaboration.

To compare variability on an abstract basis an expression combining the idea both of standard deviation and type is added here. It is found by dividing the standard deviation by the mean as a base. The result is an excellent index of variability in the form of a rate per cent. usually known as the coefficient of variability. The value of the coefficient of variation will change directly with changes of the standard deviation, and inversely with changes of the mean. For the case at hand the coefficient of variability is 54.60 and 33.28 for the bog conditions and the woodlots respectively.

The mode and the three important variation constants, together with the probable errors of the determination, which were deduced from the frequency curves in the manner described above, are as follows:

Habitat	Bog	Woodlots
Mode	3 mm.	2 mm.
Mean	3.425±0.098	1.701±0.038
Standard deviation	1.870±0.069	0.566±0.027
Coefficient of variability	54.60 ±2.55	33.28 ±2.46

The amount of variation is, as we should expect it to be, sensibly different in each of the localities selected. The extreme values for the coefficients are 54.60 and 33.28, giving a difference of 21.32. We may accept these differences in the coefficients of variability as additional proof that when organisms are introduced in changed or unusual conditions they become more or less variable. It can safely be granted that the conditions of variability which are here a function of place, are masked but little by others. In the case at hand, variability is not due to chance, but is an inevitable accompaniment of the differences in the habitat. The evidence for this statement is found especially in a forthcoming paper on the response of plants to toxic substances, and in the methods and results of experimental physiology. Here, however, the results appear to be of considerable interest as showing that by the use of the quantitative method we are passing to an equally definite and exact determination of the importance of environmental conditions.

The points brought out may be summarized thus:

(1) The data above presented show clearly that a biometric record of secondary growth in trees furnishes a very valuable criterion for the comparison of the conditions of different plant habitats. They are data involving climatic and edaphic factors which are of the greatest importance to plant life, and hence may be best correlated with functional and structural changes.

(2) The response to environment in the case of *Acer rubrum* is rapid and pronounced. The annual growth of wood automatically records in duration, intensity and quality the effect of the various ecological factors. The differences in amount and size of wood cells, in thickness of walls, extent of infiltration, etc., clearly indicate differences in type. We have here the type and the place-habit from two distinct edaphic conditions. The differences in the soil habitat have led to physiological variations which changed not only the type, but the variability and even the sign of the skewness. Quantity and quality of the wood have been affected; as products of the environment they are a measure of environmental conditions.

(3) In a study such as this the biometric data seem more valuable than long records of temperature, light, humidity, wind velocity, and others. The effect of these is included as far as they influence the plant. Greatly varying as meteorological and soil data are, it is almost impossible to combine them so as to exhibit their importance to plant growth and to climatic and edaphic centers of development. Hence the biometric point of view is an additional criterion to furnish a suitable basis for comparing ecological data, and for determining the relation of a locality to the whole range of the species, and to the direction of its migration.[1] It seems certain therefore, that if such statistical data were exhibited for various regions, climatic and edaphic centers of distribution could be clearly indicated.[2] It is hoped that investigators

[1]Adams, C. C., Southeastern U. S. as a center of geographical distribution of flora and fauna. Biological Bull., Vol. III, 1902, pp. 115-131.

[2]Transeau, E. N., Climatic centers and centers of plant distribution. Mich. Acad. of Sci., Vol. VII, 1905, pp. 73-75.

in other places will make studies similar to the one here presented for the purpose of testing the value of this criterion.

(4) It is well known that the ability of plants to transmit acquired characteristics is readily demonstrated in forest trees, where climatic influences continue to show themselves with plants grown from seed derived from different localities. It becomes a problem of practical, as well as theoretical importance to determine to what extent such differences in functional variations persist. The advantage of the biometric method in knowing definitely the behavior of plants and the effect of environment is apparent. Whether or not individuals, which have proven to be more variable, would be favorable to any selection process remains to be seen from experimental determinations.

Peat Toxins and Their Effect Upon Soils.—In connection with the experiments on the presence of injurious substances in bog water and bog soils, and their effect upon agricultural plants, the question arose whether the toxins which are harmful to plants in water cultures are injurious also to plants growing in soil containing them. This question has an added interest just now, because facts like those cited above give indications that the sterility of unproductive and "exhausted" agricultural soils may partly be caused by some toxic substance of a physiological and biochemical origin. Different workers have observed that the growth of plants often gives rise to unfavorable conditions. The data obtained from various lines of experiments all go to prove that "exhaustion" cannot always be attributed to the removal of plant nutrients from the soil by previous crops or by previous plant societies.[1]

To attempt a review of the literature on this problem would be out of place in the present chapter. Suffice it to say that the results thus far obtained point strongly to the view that decreased physiological activity of plants lies rather in the toxic condition of the soil. The experimental proof is still regarded by many as furnishing negative evidence upon the problem,[2] and hence a spirit of controversy prevails in most of the writings upon this subject. However, it can no longer be questioned that the solution of this inquiry is of great importance to agriculture. It promises to throw new light upon many interrelations of soil and plants, and appears to afford a satisfactory explanation of some of the problems connected with the association and successsion of plants, which on every other criterion would largely remain an enigma.

For the purpose of determining whether the toxins of bog water

[1]Livingston, B. E., Further studies on the properties of unproductive soils. U.S. Dept. of Agriculture, Bureau of Soils, Bull. 36. 1907.

[2]Hall, A. D., Theories of manure and fertilizer action. Science, N. S., Vol. XXVIII, 1908, pp. 617-628.

King, F. H., Toxicity as a factor in the productive capacity of soils. Science, N. S., Vol. XXVII, 1908, pp. 626-635.

are harmful also to plants growing in soils containing the injurious substances, it was decided to employ first of all a soil medium as nearly non-nutrient as possible. Quartz is one of the chief and most nearly insoluble constituents of soil. It has been shown[1] that quartz is of minor importance in the adsorption and retention of hydroxides and various neutral salts; a knowledge of its action for bog water seemed, therefore, of fundamental importance. The quartz used was obtained from the Ceramics Department of the Ohio State University. To free it from possible impurity it was subjected to a thorough washing. The air-dry quartz sand was first sifted through a sieve having meshes of 1^{mm}. Portions of about 250^{gm} each of the sifted material were placed in a large porcelain dish containing distilled water acidulated with HCl. It was usually the practice to boil the material for twenty minutes. After boiling, the supernatant liquid was decanted and fresh distilled water was added. A similar washing was carried out in *aqua regia* and later again in dilute KOH. The quartz was then washed repeatedly in boiling distilled water and finally dried at 212° F. (100° C.), until ready for use.

The bog water used in these experiments was collected from the same central station on the bog island as described in the earlier part of this chapter. The solution is relatively clear, the suspended particles imparting to it a slight tinge from olive-green to brown. It is very little acid to phenolphthalein, but alkaline to methyl orange.

Since no experiments had been made thus far to ascertain how much of the toxic property of the bog water is removed by a given quantity of an adsorbing agent, series of ten cultures were prepared for this purpose. Seven of the cultures consisted of 400^{cc} each of bog water, to which was added sterilized quartz in quantities equivalent to the following volumes: 25, 50, 75, 100, 125, 150, and 200^{cc} respectively; that is the quantities were chosen in volumes equal to a definite fraction of the volume of bog water used. The bog water and the quartz sand were shaken together in glass-stoppered bottles, and left standing for several days. When ready for use the liquid was decanted and placed in half-liter Mason jars, covered with black paper. Three control cultures were added, consisting respectively of untreated bog water, boiled bog water, and distilled water. The wheat seedlings used for these cultures were germinated in sawdust until 4 to 5^{cm} high. In later experiments the seedlings were germinated in quartz sand. They were then carefully washed in distilled water and transplanted to the water cultures. Never less than six seedlings were used in any experiment. It should be observed also that the seedlings were selected individuals out of a large number of plants. The corks used were previously sterilized and paraffined. Growth was measured by trans-

[1]Briggs, L. J., On the adsorption of water vapor and of certain salts in aqueous solution by quartz. Am. Jour. Phys. Chem., Vol. IX, 1905, pp. 617-640.

piration and the green and dry weight of plants. The cultures stood side by side in the university greenhouse in diffused light. The weekly atmometer readings varied between 176 and 186^{cc}. Below, in table 12, are given toxiticity figures for bog water collected at two periods. Column I gives data for bog water collected September 12, 1908, nearly at the end of one of the most severe droughts that have been experienced in Ohio; the bog water for column II was brought to the laboratory October 16, soon after the first rains. The evidence derived from similar experiments with bog water collected at intervals of one month during the year is omitted, showing, as it does, considerable repetition. It should be noted, however, that the variation in the range of results for the seasons is considerable.

TABLE 12

ADSORPTION OF BOG TOXINS BY QUARTZ SAND

Solution.	Corresponding Place on Curve.	Total Transpiration for 15 Days, in Grams.	
		I. Sept. 12.	II. Oct. 16.
1. Distilled water 400^{cc}	A	7.50	7.50
2. Bog water 400^{cc}, untreated	B	10.26	14.90
3. Bog water 400^{cc}, boiled	B'	----	54.22
4. Bog water 400^{cc} + 25^{cc} SiO_2	C	22.70	25.50
5. Bog water 400^{cc} + 50^{cc} SiO_2	D	----	18.17
6. Bog water 400^{cc} + 75^{cc} SiO_2	E	39.28	13.83
7. Bog water 400^{cc} + 100^{cc} SiO_2	F	----	13.56
8. Bog water 400^{cc} + 125^{cc} SiO_2	G	48.73	----
9. Bog water 400^{cc} + 150^{cc} SiO_2	H	----	12.87
10. Bog water 400^{cc} + 200^{cc} SiO_2	K	18.60	12.55

The results for these two dates have been plotted in Fig. 23. The growth rate in terms of transpiration is indicated on the axis of ordinates, and the progressive addition of quartz to bog water is shown on the axis of abscissas.

Before taking up the facts brought out in this series of experiments, another part of the investigation must be mentioned. The foregoing observations suggested the query whether results obtained with soils of varying quality, fineness, and adsorbing surface would show that the toxic strengths of the same bog-water solution have approximately the same relation to each other irrespective of the nature of the filter used. It was intended to use types of soil ranging progressively through the weathering products from feldspars to kaolin. But the feldspars are highly alterable minerals, and the chemical products of feldspathic and granitic rock-decomposition are extremely varied;[1] in the residues, however, which remain after leaching, free silica as quartz, and a number of rather indefinite substances known as clays,

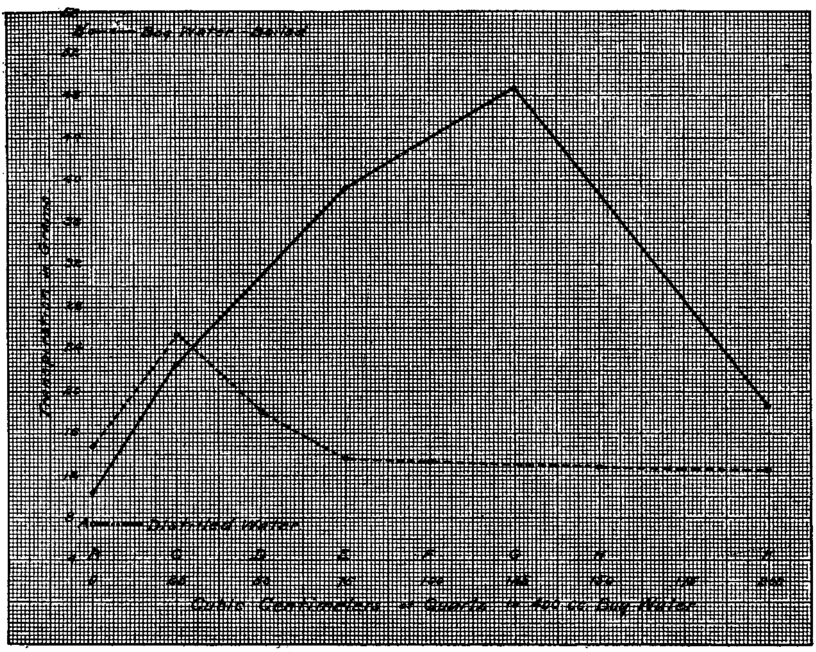

Fig. 23.—Diagram showing growth-rate of wheat seedlings in treated bog water. The ordinates represent transpiration in grams; the abscissas show the progressive addition of quartz to bog water. Unbroken lines for bog water collected September 12, 1908. Broken lines for bog water of October 16, 1908. Broken line single dotted for boiled bog water; broken line double dotted for distilled water.

are the most abundant. In the present case the efficiency of the following substances, characteristic of the final residue of soil-forming rocks, and their allied substances, was tested: SiO_2 coarse; SiO_2 fine; kaolin; $CaCO_3$; SiC; and C in the form of air-dried humus. The materials were obtained through the courtesy of Mr. C. H. Kerr of the Carborundum Company, Niagara Falls, New York. They are among the most insoluble substances known, and of great purity, which makes

[1] Clark, F. W., The data of geochemistry. U. S. Geol. Survey, Bull. 330. 1908.

them of special value in this investigation. The chemical analysis of these materials is as follows:

TABLE 13

Material.	Quartz.	Kaolin.	Carborundum.
C	-----	-----	29.71
O	-----	-----	0.45
Si	-----	-----	69.40
SiO_2	99.56	45.35	-----
Al_2O_3	0.40	38.86	0.28
CaO	-----	0.35	0.15
Fe_2O_3	-----	0.38	-----
K_2O	-----	0.61	-----
MgO	-----	0.31	0.05
Na_2O	-----	0.31	-----
Ignition	0.14	13.80	-----

The physical composition of the materials employed was determined by microscopic examination. Mechanical analysis was made with the aid of a centrifuge and for the coarser components by means of their different rates of subsidence in water. The relative percentages by weight of the different component particles in each group is as follows:

TABLE 14

Material.	SiO_2 coarse.	SiO_2 fine.	Koalin.	SiC.
Sand 0.5 — 0.25mm	100	-----	-----	-----
Vey fine sand 0.1 — 0.05mm	---	6.5	2.4	79.4
Silt 0.05 — 0.005mm	---	80.8	61.8	16.6
Clay 0.005 — 0.0mm	---	12.9	35.7	4.5

To obtain the surface area of spherical particles it is only necessary to invert the value of the mean diameter of the particles for each group. This surface factor is then multiplied by the fractional amount of the quantity of the sample having particles of these mean diameters. A mathematical calculation of the surface area of quartz flour, carborundum, or other crystalline bodies with irregular surfaces, however, is not so readily obtained. It may be that adsorption of toxins and absorption of vapors and gases are subject to the same conditions.[1] Per-

[1]Patten, H. E., and Gallagher, F. E., Absorption of vapors and gases by soils. U. S. Dept. of Agriculture, Bureau of Soils, Bull. 51. 1908.

haps by taking measurements upon the rate of retention of a silver salt, one may secure an indirect method for the calculation of the surface of these bodies. A curve showing how the adsorption data are related to the surface presented by the grains of the different soils used, though of interest, is not a question at issue in this discussion, but it is hoped to continue this problem further, and in a more quantitative manner.

The precaution was taken to allow contact between the solution and the solid bodies for thirty minutes only, in order to reduce to a minimum the low solubility of the materials[1] and the possible action of the solution upon the solids. The amounts used in each case, and the effect of these insoluble substances on the toxic action of bog water collected January 30, 1909, are given below in table 15. The transpiration data covered a period of fifteen days and are for six wheat plants in each solution.

TABLE 15

ADSORPTION OF BOG TOXINS BY INSOLUBLE SUBSTANCES

Solution.	Transpiration in Grams; Six Wheat Seedlings in Each Solution.			
	5th day.	10th day.	15th day.	Total.
1. Bog water 400cc, untreated	4.30	8.55	3.65	16.50
2. Bog water 400cc, filtered	4.90	10.35	6.75	22.00
3. Bog water 400cc + 15cc SiO_2 (coarse)	5.25	10.00	7.35	22.60
4. Bog water 400cc + 25cc SiO_2 (coarse)	7.20	12.85	9.80	29.85
5. Bog water 400cc + 50cc SiO_2 (coarse)	7.00	13.55	10.65	31.20
6. Bog water 400cc + 15cc SiO_2 (fine)	8.60	19.10	13.50	41.20
7. Bog water 400cc + 25cc SiO_2 (fine)	6.70	19.00	16.60	42.30
8. Bog water 400cc + 50cc SiO_2 (fine)	7.68	16.40	13.10	37.18
9. Bog water 400cc + 15cc Kaolin	9.10	20.00	16.25	45.35
10. Bog water 400cc + 25cc Kaolin	9.65	19.32	21.58	50.55
11. Bog water 400cc + 50cc Kaolin	9.95	20.10	23.40	53.45
12. Bog water 400cc + 150cc Kaolin	11.98	22.20	16.07	50.25
13. Bog water 400cc + 15cc $CaCO_3$	10.90	20.50	24.70	56.10
14. Bog water 400cc + 25cc $CaCO_3$	10.48	20.70	26.50	57.68
15. Bog water 400cc + 50cc $CaCO_3$	10.07	19.17	23.35	52.52
16. Bog water 400cc + 15cc SiC (fine)	11.23	21.25	25.60	58.08
17. Bog water 400cc + 25cc SiC (fine)	10.90	17.50*	21.20*	48.60*
18. Bog water 400cc + 50cc SiC (fine)	11.25	23.00	29.10	63.60
19. Bog water 400cc + 15cc C (humus)	11.00	25.15	40.65	76.80
20. Bog water 400cc + 25cc C (humus)	8.30	16.70	41.90	66.90
21. Bog water 400cc + 150cc C (humus)	8.55	22.15	24.80	55.50

*5 plants in culture.

Several facts seem to be clearly brought out in the above data. A comparison of the toxicity figures of bog water collected at intervals during the year indicates that the amount of toxic substances in solu-

[1]Comey, A. M., Dictionary of chemical solubilities. 1896.

tion differs very appreciably within the year In all cases the physiological studies show that the adsorbing substances actually remove definite quantities of bog toxins. In contrasting the efficiency of the various amounts of adsorbents used, the important facts at the outset are these. Different physiological phases result from the progressive increase of an adsorbing substance. The bog-water solution, fatal in its effect at some seasons, gives an increase in growth-rate when adsorption removes a sufficient amount of the toxic ingredient. The effect is virtually one of dilution. Doubling of the amount of the adsorbent brings the growth-rate into a physiological phase marked by a greater functional activity. Further addition, and its consequent further dilution in toxicity, carries with it a corresponding intensification in growth-rate. The appearance of the plants especially in the development of the root system, follows the transpiration figures very closely. Stimulation and tolerance rise to a maximum. But with successively larger amounts of adsorbent, the optimum rate of transpiration can be neither increased nor maintained. It falls off, regularly and rapidly at first, subsequently less rapidly, until the effect of the solution is practically that of distilled water.[1] Greater dilution and consequent increase in rate of transpiration does not express, therefore, the whole truth. Other and less injurious substances are also adsorbed; and the rate of transpiration is seen to be the product of a coördination of factors. In bog water with very slight toxicity, the course of the experiment shows that the maximum acceleration phase deviates very sensibly toward the growth-rate approximated in the control, i. e., the untreated bog water.

On account of the difference in size of particles, there naturally follows a corresponding difference in the amount of adsorption. Compared with kaolin, calcium carbonate, carborundum, and carbon (as lampblack or humus), the adsorptive power of quartz is relatively low. It will be seen that the optimum rate of transpiration of the tenth day in solutions 3 to 9, table 15, is soon succeeded by a minimum. This is due to the action of toxic substances still present; for upon further addition of adsorbents the minimum at the end of the fifteenth day is succeeded by a higher rate of transpiration. Filters of finer grain are more beneficial, while the adsorptive power of humus is very much higher than that of any of the crystalline substances used. The optimum and maximum rates of transpiration occur on the fifteenth and twentieth day and lie near together. Reference to the total amount transpired shows that the adsorption of carborundum and humus is about three to four times greater than that of quartz. The transpiration data serve excellently as a basis for assigning a limit to the magnitude of the toxic effect, and as an expression of the amount of the

[1]True, R. H., and Oglevee, C. S., The effect of the presence of insoluble substances on the toxic action of poisons. Bot. Gazette, Vol. XXXIX, 1905, pp. 1-21.

unknown substance adsorbed both in terms of the total adsorption, and as a percentage of the surface factor of grains. The result with $CaCO_3$ also shows that the plants are not affected by conditions of acidity or alkalinity, and that growth seems to be more materially affected by the specific action of the organic toxins present. Whatever the nature of the filter used, that the increased tolerance of wheat seedlings to bog water is actually due to the adsorptive power of the filters is sustained by the fact that the decrease of the poisonous effects of bog water is apparently a function of surface of particles and is approximately proportionate to the quantity of the solid body used. The solution, decidedly toxic without the solid, becomes capable of supporting a more than normal growth.

The outcome of these preliminary tests is, therefore, that the conditions giving rise to decreased physiological activity, to xeromorphy, and to zonation of bog plants, are not found in the depletion or increase of mineral nutrients in bog water, nor in a low soil temperature, but lie rather in the toxicity of the soil substratum, i. e., in the production of unfavorable soil conditions.

However, experiments by the water-culture method may not always be serviceable as a safe basis for argument concerning soil conditions. A number of life relations of the plant in a water culture become changed when in the soil. In what particular manner the toxic substances are held by the adsorptive forces of the filter is not clear if judged by physical or chemical analysis.[1] The marked retention of the toxins of bog water observed may be due to causes other than a direct condensation on the surface. No experiments were made to show conclusively that the retention is not due to chemical fixation or substitution. The amount of solution thrown out of the quartz by the centrifugal machine was too small to be tested. *A priori*, it would seem that the filter used should be markedly more toxic now than the solution, when tested by physiological criteria. The presence of the adsorbing bodies in the solid should not only reduce its effectiveness when repeatedly used for improving bog water, but should replace normal growth by an abnormal retardation judged from the growth-rate made in a similar check soil culture.

To obtain evidence on this point, and to contrast the efficiency of the various constituents of agricultural soils for adsorption, a series of experiments were made with quartz, river sand, field clay, and humus soil. The air-dry soils were sifted through a sieve with meshes of 1^{mm}. Portions of 400^{cc} of the sifted soils were each placed in glass-stoppered jars containing $1{,}200^{cc}$ of bog water. The glassware employed in all of the experiments cited was treated with a solution of potassium dichromate and sulfuric acid, and repeatedly rinsed in distilled water previous to use. The mixtures of bog water and soil were left standing

[1]Michaelis, L., Dynamic der Oberflächen. Dresden, 1909.

in the dark room for three days. To insure thorough contact between the bog water and the soil, the solution was occasionally shaken. When ready for use the liquid was filtered off, and portions of 400^{cc} of the liquid from each soil type were used as water-culture experiments in the manner described above. For the investigation of the relative fertility of the soils used as filters, earthenware pots were employed. The pots were new and each of about 300^{cc} capacity (8^{cm} in diameter, 8.5^{cm} deep). They were thoroughly cleaned and dried in an oven at 262° F. (110°C.), and later immersed in heated paraffin. To each paraffined pot was added 200^{cc} of the contaminated soil well pressed into the bottom and sides of the pots. It was recognized that difficulties of obtaining good contact between the soil and the walls of the pot would be probable. In the air space along the walls usually by far the greater proportion of plant roots are developed, and the wire-basket method as recommended by the Bureau of Soils of the U. S. Departmemt of Agriculture (Bull. 23) is, therefore, more desirable. But the form of retainer here described was found to be wholly satisfactory. In no case were evidences found of roots growing more freely at the sides of the pot than in the center. The experiments were repeated later by the wire-basket method with the same results. Six wheat seedlings were transplanted in a row in the soil of each pot. In identically the same manner a series of duplicate cultures with the untreated soils were prepared to serve for comparison with the behavior of wheat seedlings in the contaminated soils. The filled pots were then weighed and placed in the greenhouse where they stood side by side. Direct sunlight was avoided by cloth screens. Only one of the experiments need be given; table 16 gives a summary of the results obtained with bog water collected September 12, 1908. The percentage increase is calculated upon the basis of the quantities marked zero (0), considering them as unity for the respective series. The photograph (Fig. 24) shows these plants at the end of the experiment.

TABLE 16

ADSORPTION OF BOG TOXINS BY SOILS

Solution.	Average Length in *cm.*		Percentage Increase.		
	Tops.	Roots.	Transpiration.	Green weight.	Dry Weight.
1. Bog water untreated	15.8	5.3	0	0	0
2. Bog water quartz-filtered	20.8	42.0	338.	134.	56.
5. Bog water clay-filtered	19.9	11.4	154.	68.	11.
8. Bog water humus-filtered	30.5	15.6	805.	220.	84.
3. Contaminated quartz soil	22.0	12.3	---	0	0
6. Contaminated clay soil	22.2	6.6	---	0	0
9. Contaminated humus soil	21.9	6.2	---	0	0
4. Control quartz soil	24.7	9.6	---	8.	20.
7. Control clay soil	26.0	11.7	---	23.	5.
10. Control humus soil	30.7	13.5	---	86.	55.

Again, it is evident that the addition of solids has increased the tolerance of the seedlings to bog water. The improvement was marked during the entire period of experimentation. The presence of the toxic substances in small amounts exerted a noticeable stimulating effect, while the plants in the control bog water gave every indication that they would be unable to survive an exposure of a normal growing period. The last mentioned point has been repeatedly tested also in field-work. It seems as if the roots, and especially the more minute root hairs, of the plants in the untreated bog water served as adsorbing surfaces. The roots are brownish in color and jelly-like in consistency; deposited upon their surfaces are found numerous colored substances, as the result

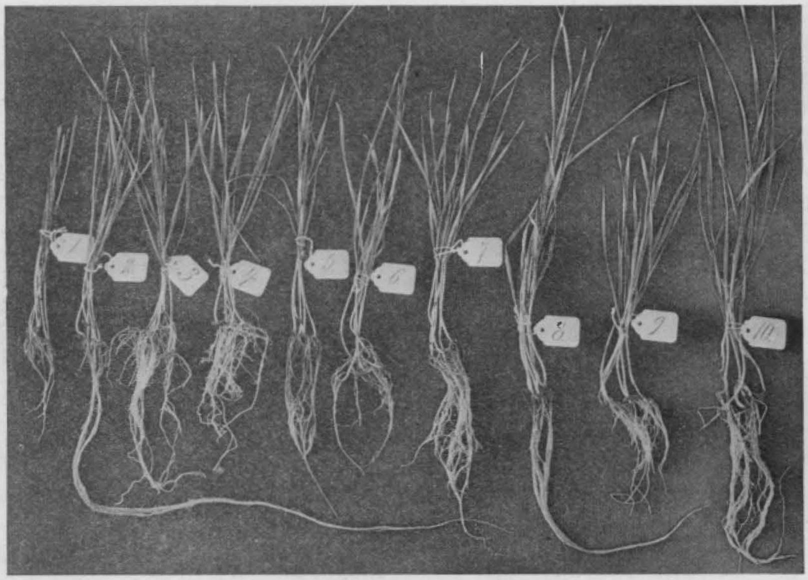

Fig. 24.—Growth of wheat plants in various cultures of bog water. Numbers as in Table 16.

of the oxidizing action of the roots. The nature of these substances is still under investigation. A general decay of the growing tips is noticeable, showing that the oxidizing action of the plants upon the toxic substances went far toward decreasing their harmful effect, but could not entirely overcome them. The effectiveness of adding the insoluble solids proves, therefore, very conclusively that the source of the harmful condition must logically be looked for in the solution and not in the condition of the plants themselves. The difference in the tops as well as in the roots of the plants from the various cultures is very striking. The stimulating effect is less marked in the solutions filtered through clay and humus, because of the greater adsorptive power of these substances; yet the increase in the green and dry weight of plants is about twice that in the untreated bog water, while transpiration has increased almost ten-fold. The introduced materials have had their adsorptive action, but it is evident also that chemical reaction enters in the case of the common types of garden soil.

We come, finally, to a consideration of the effects of bog toxins upon soils. It is to be noted that the poisonous action of bog toxins is more harmful when the plants are immersed in the solution, than when grown in the contaminated soil cultures. That the poisonous matter injurious to plant growth is present in the soils used as filters is seen upon comparison with the controls. Manifestly, the theory of lack of O_2 in bog water or in bog soils as the cause of xeromorphy does not satisfactorily account for the results, because water cultures usually have less O_2 than any soil medium. The transpiration data for boiled bog water (table 12, page 325) are further evidence in this direction. The inadequacy of the theory of low substratum temperature is, for this locality, equally obvious. That the action cannot be attributed to large amounts of dissolved substances has been shown in the determination of the osmotic pressure of bog water in Chapter XI. The garden soils contain a much larger amount of nutrient ingredients than bog water, and hence the presence of those salts should tend to increase the growth-rate. No such increase in activity occurred. The length of time during which the wheat plants were allowed to grow is palpably insufficient to "exhaust" or contaminate the soils. The retardation seen in the contaminated soils is lacking the corresponding normal average in dry weight of plants to an amount of 18 per cent., 3 per cent., and 36 per cent. for quartz, clay, and humus respectively. From the results it may be concluded that the adsorption and retention capacity of soil for toxins is generally higher the greater its content of humus. It was shown elsewhere that a bog-water solution well aerated, or upon long standing with exposure to air, lost its injurious properties. When plants are grown in this oxidized solution it is found that the solution becomes decidedly beneficial to plant growth. These results are also obtained with the contaminated soils. When first used they exert a distinctly injurious effect. If the amount of water transpired by the plants is replaced by bog water, the soils become more toxic Decrease in toxicity always follows aeration of the soil and drainage; and since the physical conditions mainly determine the amount of oxidation, these are of greater consequence in restoring the fertility to the soil.

Summary.—The available information of the study here reported may be summarized as follows:

1. Many swamp and muck soils exhibit a sterility which cannot be remedied by drainage or by the addition of fertilizers.

2. The sterility appears to be most marked where investigations

on the physiological effects of bog water and bog soils indicate a greater amount and activity of bog toxins.

3. The production of bog toxins is due to a number of physical, biological and chemical factors. One can only conclude that the chemical constitution of bog water and bog soils at a given moment conditions toxicity; and that the excretion from roots and rhizomes of plants is, possibly, one of the variables of the conditioning factors.

4. In untreated bog water there are found deposited upon the roots of wheat plants numerous colored substances as the result of the oxidizing action of roots. The general decay of the root tips indicates that the oxidizing activity is insufficient to decrease the harmful effects of bog toxins.

5. It is possible that ecesis, association, and succession of plants depend primarily upon respiration, and that in respiration bog plants differ from other plants.

6. Treating bog water with an insoluble adsorbing agent is invariably beneficial.

7. Different physiological phases result from the progressive addition of an adsorbing substance. With coarser-grained materials the low optimum rate of transpiration is soon succeeded by a minimum which is due to the action of toxic substances still present.

8. Finer-grained insoluble bodies are more beneficial. The response to toxic substances, when present in small amounts, leads to acceleration of growth. The period of growth is more prolonged and the optimum and maximum rate of transpiration lie near together.

9. The adsorptive action of carborundum and humus is about four times greater than that of quartz; the capacity of soils for retaining toxins is therefore higher the greater the content of humus.

10. The decrease of the poisonous effect of bog water is probably a function of the surface of the particles; it is relatively proportionate to the quantity of the solid body used.

11. In agricultural soils used as adsorbents the presence of the absorbed unknown toxins replaces normal growth by an abnormal retardation. Fertility is restored through aeration, that is, after time enough has elapsed for the oxidation of the injurious substances.

12. The contaminated condition of agricultural soils and the consequent decreased physiological activity of the plants grown in them still further indicate that xeromorphy cannot be due to acidity, lack of oxygen, low temperature etc., of the soil substratum; that is, the factors heretofore cited are only in part the cause of xeromorphy.

In view of the evidence presented above, the writer believes that these facts in the action of bog water upon soils justify the conclusion that there are present in bog water and in bog soils injurious substances which are, at least in part, the cause of xeromorphy in plants, and of decreased fertility in bog soils.

The Nature of the Absorption and Tolerance of Plants in Bogs.— Interest in the study of the absorption and in the varying degree of tolerance and resistance of plants growing in Ohio bogs has been coincident with the determination of the quantitative nature of the habitat factors, but it has been only through an appreciation of the subordinate value of the atmospheric and other physical habitat factors that attention could be given to the special diosmotic properties of the plants and of the substances absorbed together with the changes which the penetrating substances produce upon the plants. The changes which the substances undergo internally or externally to the absorbing organ or the cell are relationships of equal importance in the problem of nutritive metabolism, but a discussion of them cannot be attempted as yet.

The evidence as to the rôle of physical, chemical and biotic habitat factors, derived from the study of local bog vegetation, is brought out in greater detail in the following chapters. It is sufficient to point out that atmospheric conditions, though of importance, are not the limiting influences for the growth of plants upon Ohio peat deposits. The various physical environmental relations usually cited are inadequate to account for the failure of some of the agricultural plants to thrive and for the survival of others. And since differences in light intensity, in special absorption powers of roots for peaty substrata, since fungal micorhiza, and morphological limitations in the absorption and in the conduction of water, do not enter into the problem with the agricultural plants used for the test-experiments, it seeems timely to consider in more detail the specific rôle of the organic decomposition products in the relation between the required quantity of available water and the quantity absorbed by the plants.

That some sort of a correlated mechanism, acting within certain limits, is of the utmost importance in these species seems evident from the fact that while the presence of structural modifications is generally regarded as a reaction in favor of a bog vegetation, the most noteworthy characteristic which enables the invading plants to resist the unfavorable conditions is a greater elasticity of functions, and perhaps some specific place-function. What is the mechanism connected with the failure of many agricultural plants to thrive in peat soils and in solutions of bog water? With what critical features, either as products of habitat or congenital variation, are the surviving plants provided by nature to regulate or control the absorption of injurious organic compounds, and what are the pathological aspects which involve dwarfing, leaf-fall and general senescence in most invading species alien to the habitat?

A knowledge of the limits of functional variation within a known species and its several varieties should prove very essential as to the role and the range of the individual and genetic differences in the plants themselves, and the ability of the plants to inhibit the absorption of deleterious substances, or to neutralize the injurious action of the substratum.

In the present preliminary discussion data are submitted which were obtained from experiments in the laboratory with several standard varieties of grain sorghums, alfalfa and bean. The seeds were obtained from the United States Department of Agriculture through the office of seed distribution. The seeds were germinated in sterilized quartz sand and treated in a manner described in the earlier part of this chapter. The physiological tests were made in bog water from the central (cranberry-sphagnum) station on Cranberry Island at Buckeye Lake, Ohio. All experiments were made in duplicate series. Paper-covered Mason jars were used, containing 500 cc. of untreated bog water. The following selected series in tables 17 to 19 is especially suggestive and typical.

The tables show at a glance which of the varieties are the more efficient in counteracting the effects of injurious organic compounds. Not only the relative transpiration quantities but also the morphological effects, as shown by the general appearance of roots and leaves, bear out the observation.

Especially in bog water of greater toxicity than that of the date in the above series, the plants were in strong contrast to each other, functioning less readily also as the active mass of bacterial products increased (table 22).

The rate of growth varied considerably according to the amount of transpiration and to the supply of available water. When the rate of transpiration decreased the root tips and the tops made but slight growth. The roots were discolored for some distance from the tip, appeared gelatinous, and not only their surface but the meristematic tissue seemed injured, inhibiting the formation of new laterals. The leaves were short and unfolded imperfectly. At the beginning of the experiment the roots of the stronger plants were able to counteract the injurious effect to a slight extent; light-brown insoluble substances appeared deposited upon the surface of the roots. In dilute solutions of bog water the roots remained white. Invariably, however, the toxicity was lessened most in plants whose ability to counteract the harmful effects was most pronounced. The decreased permeability of the plasmatic membrane of the cells of the root-tips favored their efficiency in selective absorption and in growth.

A characteristic behaviour became evident in the increase of green weight of the plants in the dilute solutions, and in the observation that this effect was far from being uniform in all the cultures. The deleterious action of bog water was, on the whole, less marked upon the tops than upon the roots; nevertheless the green weight of some of the plants with a lower transpiration value was greater than that of the plants transpiring more strongly. Examples are numbers 3, 5 and 7 in table 17; 2 and 5 in table 18; 4 and 6 in table 19; 7 and 10 in table 22 of Chapter X.

TABLE 17.

TRANSPIRATION DATA FOR VARIETIES OF GRAIN SORGHUMS[1] IN BOG WATER, MARCH 6-24, 1910

Variety of Sorghum.	Transpiration in grams.	Green weight produced.	Water required for 1 gram of green matter.
1. Milo	106.15	2.59	40.95
2. White Durra	91.05	2.18	42.98
3. Dwarf Milo	86.70	2.87	30.17
4. Dagdi Durra	78.95	1.89	41.70
5. White Kowliang	78.32	2.92	26.08
6. Blackhull Kaffir	69.95	1.40	49.85
7. Brown Kowliang	55.65	1.46	37.98
8. Red Kaffir	52.90	1.28	41.34

Atmometer: 25 cc. daily average.

TABLE 18.

TRANSPIRATION DATA OF VARIETIES OF ALFALFA IN BOG WATER, MAY 6-26, 1910

Variety of Alfalfa.	Transpiration in grams.	Green weight produced.	Water required for 1 gram of green matter.
1. Medicago falcata	11.50	1.48	7.77
2. var. 16399 (Washington)	11.86	1.28	5.20
3. var. 23625	8.72	0.99	8.80
4. var. 9359 (Turkestan)	7.32	0.59	12.40
5. Sand Lucerne 20457	11.93	2.21	5.40

Atmometer: 18.9 cc. daily average.

TABLE 19.

TRANSPIRATION DATA OF SPECIES AND VARIETIES OF BEAN IN BOG WATER, FEBRUARY 24-MARCH 11, 1910

Species and Varieties.	Transpiration in grams.	Green weight produced.	Water required for 1 gram of green matter.
1. Dolichos 22025	150.68	3.75	40.18
2. Dolichos 8542	99.54	1.52	65.61
3. Phaseolus mungo var. 18310	66.46	1.34	49.59
4. var. 17096	69.98	2.32	30.16
5. Phaseolus mungo	56.35	1.24	45.32
6. Guar	36.57	1.21	32.23

Atmometer: 7.3 cc. daily average.

[1]Ball, C. R., The History and Distribution of Sorghum. U. S. Dept. of Agriculture, Bureau of Plant Industry, Bull. 175, 1910.

It is quite generally known that rapid growth is usually accompanied by active respiration, and hence the slowly developing plants are able to increase in dry weight upon a smaller quantity of water absorbed and transpired. Moreover, it seems clear, from the normal appearance of the roots of these plants, that the injurious substances have an entirely different effect upon some varieties of plants from that observed in others and that the marked difference is undoubtedly due to the nutritive value of the assimilable organic compounds. This particular feature of variability in nutritive metabolism is so characteristic and striking in agreement with the several experiments which were conducted, that analyses with reference especially to the ratio between the carbon and nitrogen content of the plants are much to be desired. Additional evidence of a similar nature is derived from experiments of more recent date cited in Chapter X, p. 354. Tests on the availability of nitrogen in peat have been made by a number of workers, but mostly upon sun-dry or kiln-dry peat, the solubility of which in water is very low (tables 29-30). The results confirm, however, both an increase in the production of dry matter in plants, and of dry matter relatively richer in the amount of nitrogen, as compared with the percentage in plants from soils lacking peat.[1]

The fact that to many plants, bog toxins are injurious at one concentration but not at another, and that further dilution carries with it a corresponding intensification in growth-rate, shows the inefficiency of the usual analytical methods of the organic chemist. They give no clue why some water-soluble substances are taken up by the cells of one species of plants and others not. Solubility of the substance in the continuous medium and in the membrane is the prerequisite to osmosis and to penetration into living cells.[2] Neither the properties, the chemical formula nor their effect upon transpiration alone afford an indication as to the physiological importance of bog toxins, or their differential permeability. In addition new analyses of peat, of wood and of bog plants from various zones with reference especially to the ratio between the carbon and nitrogen content should be carried out.

Another point that should be noted in this connection is the obvious difference in the water requirements of the plants. It seems that the existing differences in the various colloids in cells tend toward inequalities in the amount of water or solutes absorbed and held by the different varieties of species. Moreover, water and its solutes, whether organic compounds or inorganic salts, are as a general rule taken up in a different

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[1] Haskins, H. D., The utilization of peat in agriculture. Massachusetts Sta. Rept. pt. 2, 1909, pp. 39-45.

Lipman, J. G., Report of the Soil Chemist and Bacteriologist of the New Jersey Agri. Exper. Sta., 1910, pp. 188-195.

[2] Czapek, F., Ueber eine Methode zur direkten Bestimmung der Oberflächenspannung der Plasmahaut von Pflanzenzellen. Jena, 1911.

Lepeschkin, W. W., Zur Kenntniss der chemischen Zusammensetzung der Plasmamembran. Ber. deut. bot. Ges., Bd. XXIX, 1911, pp. 247-260.

ratio from that existing in the substratum. Inasmuch as the amount of mineral salts in bog soils (table 32) and the amount used in the growth of bog plants (p. 371) is very small, and since the lack of larger quantities is not a factor in the succession of bog associations, the most fundamental distinction is that which controls the water supply. A method of determining the ratio between ash and the yield in organic compounds on the basis of the water requirement of plants for the period of their growth would have the merit of convenience, and, it must be admitted, the accuracy which is often questionable in the unit employed and as preferably expressed in agricultural literature. The unit of water requirement now used in agricultural texts for ten different economic species is 450 pounds of water for one pound of dry matter produced. Data of that character do not place the classification and comparison of soils, and correlations with fertility itself, with season, age of plants, maximum growing period, and ripening, on a measurable basis. The unit is numerically inaccurate and does not express the fundamental and casual relations.

Experiments upon the transpiration value of bog plants in relation to structure and habitat have shown that the data can not always be expressed satisfactorily in the *gm²h* system. Transpiration is a reciprocal relation. It is affected by the mechanism for absorption, by the conditions which react upon the absorbing roots, and it is associated with chlorophyll activity and the absorption of carbon dioxide in the vertical gradient. Transpiration in the lower, more humid stratum of a bog meadow is often slight for days at a time. The luxuriousness of the vegetation and the amount of dry matter produced do not vary in this case with the transpiration quantity, but with protoplasmic permeability, permitting of exchanges by solubility, and with the active enzymatic agents within the cells which effect the assimilation or the destruction of the substances in the external medium.

It remains to be ascertained to what extent the absence of any mineral salt may lead to the unbalanced condition which induces the general pathological effects upon agricultural plants, and whether any one of the salts employed in fertilizers may in part or entirely counteract the injurious effects of peat and humus soils.[1] Plant physiological and particularly agricultural literature contains numerous references to the rôle of mineral salts as nutriments. It must be candidly admitted that the effects of the various mineral salts produced upon the plant or the cell are far more easily formulated than proved, and that a satisfactory interpretation is not possible as yet. It is now known that in the preparation of mineral solutions for plants a certain ratio of the different salts is required, and that basic ions may be retained by the selective adsorbent power of cell colloids.[2] It would be of special interest to note

[1]Schreiner, O., and Skinner, J. J., The toxic action of organic compounds as modified by fertilizer salts. Bot. Gaz., Vol. LIV, 1912, pp. 31-48.

[2]Baumann, A., und Gully, E., Untersuchungen über die Humussäuren. Mitt. bayr. Moorkulturanstalt, Heft 4, 1910.

in some detail the relation of potassium and calcium compounds, and the suitable concentrations required to counteract the toxicity of the deleterious substances in peat soils. The fact that water and salts are as a general rule taken up in a different ratio, differing also according to the species of plants used as an indicator, shows that the relation in balanced solutions affects, and is determined primarily by the diosmotic properties of the protoplasmic membrane and its responsive processes.[1] The direct effect of mineral salts on the protoplasmic membrane is undoubtedly of greater importance than their supposedly special nutrient value. Tolerance and resistance of plants to physiologically deleterious substances, it may be added, are not osmotic pressure relations to bog water, nor is the absorption of water a function of it. A study of the magnitude of the internal osmotic pressure occurring in the roots and in the foliage of bog plants as related to bog conditions has not been carried very far as yet; wheat plants growing in bog soils do not, however, show more than the usual pressure[2] isotonic with a .3 normal solution of potassium nitrate.

Aside from the nutritive inequalities of organic peat soil constituents it is worth while to study more closely the various structural modifications that appear in plants indigenous to the habitat, in the less fit invading plants, and in those which survive. The form of invading plants is frequently altered, as is shown in dwarfing, in the reduction of the number and the size of leaves, in the loss of buds and branches, in the rapid aging of the plants. This indicates the extent in which the various functional mechanisms involved such as absorption, conduction, and growth are interrelated and coördinated. Every green plant is undoubtedly able to a certain extent to assimilate nitrogenous and other organic compounds. Plants which grow preferably on humus and peat soils must have special absorptive powers, but little is known, as yet, to what extent the roots themselves exert a direct solvent action, enzymic or otherwise, in rendering the peat available for assimilation, and how far fungal micorhiza, which form symbiotic unions, are of importance.

The contents of this chapter may be stated briefly as follows:

The physiological effect of bog water and bog soil to a great extent plays an important primary role in the determination of the flora which can best succeed upon peat deposits. It was shown that a number of cultivated plants and plants from different but neighboring habitats in the same locality fail to develop normally in peat soil when grown in the bog or under laboratory conditions, and that the toxicity of the habitat appeared, therefore, to exert a marked influence in determining not only the character but also the distribution of plants within the same

[1]Osterhout, W. J. V., The permeability of living cells to salts in pure and balanced solutions. Science, N. S., Vol. XXXIV, 1911, pp. 187-189.

[2]Fitting, H., Die Wasserversorgung und die osmotischen Druckverhaltnisse der Wustenpflanzen. Zeitschr. f. Bot., Vol. 1911, pp. 209-275.

habitat. A difference was shown to exist between different species in their power of resistance to the toxic action of the substratum, so as to leave no doubt that some species of plants are better adapted than others to growth in soils containing relatively large amounts of injurious substances. That the stunted plants in these experiments have not lost their capacity for absorption and growth can be readily demonstrated. The plants resume their natural functions as soon as they are placed in dilutions less fatal in their effects. In contrasting the differences in physiological activity it was shown that various phases of absorption and transpiration result from the progressive addition to the medium of chemically inert filtering materials. Types of soil were used ranging from the weathering products of soil-forming rocks to the completely oxidized products characteristic as the final residue. Incidentally it was shown that the normal growth of the plants in the uncontaminated soils was replaced by an abnormal retardation. In the main, however, the study indicated that upon extraction of the injurious substances by means of insoluble adsorbing bodies not only the differences between various species as to their tolerance and resistance were less pronounced, but also the differences in toxicity existing between the several zones within the same habitat. The selective action of the habitat was shown to be greatly diminished upon the removal of the injurious organic substances accumulating in the peat substratum. The conclusion was drawn that the relative power in bog plants for absorbing or rejecting the injurious constituents of bog soils and bog water was, therefore, the limiting factor, controlling the survival value of invading species and of plants native to the habitat. The roots of bog xerophytes are not much shorter than those of other plants; the lateral roots develop extensively, and the prevalent direction of root-growth is horizontal rather than downward. This reaction cannot be regarded as one due to low soil temperature or to a slight oxygen content. The inhibitory factor for root-growth which increases with depth is the reducing action of the substratum, and the incomplete disintegration of organic compounds. It is now well known that certain root enzymes are oxidizing agents which assist in the destruction of the deleterious compounds in soils of an organic nature, and that the oxidizing action becomes lessened when the injurious organic substances are in excess. The wide variations in this functional reaction are probably of greater importance than external factors. It is a tenable hypothesis that the survival or the extinction of invaders may depend upon the degree of functional plasticity.

The experiments here cited furnish nothing more than an indication of the relative importance of some of the factors involved. The weight of evidence is obviously incomplete, for numerous important considerations have received no attention whatever in the present chapter. The problem of absorption is not one of simple solution but an intricate and coördinated process, and much needs to be known of the quantitative energy relations between plants and habitat and the organization of the protoplasmic membrane of absorbing root-cells. From the present study the following relations may be summarized:

1. In view of the widely differing behaviour of agricultural varieties in a bog water solution, and the interesting observation that the plants respond differently to the same solution, the conclusion is inevitable that here the source of the difference must logically be looked for not in the solution alone, but in the condition of the plants as well.

2. Since certain of the organic compounds eventually penetrate the protoplasmic membrane of absorbing organs and inhibit growth, it is evident that much importance must be ascribed to the influecne exerted upon the plasmatic membrane, the consequent differences in its diosmotic properties, and to the pathological changes induced which accompany the absorption of the injurious substances.

3. Some plants in contact with peat soil solutions may cause the organic constituents to be precipitated in an insoluble form.

4. In other plants the different organic carbon and nitrogen compounds arising in peat through the activity of microörganisms may be absorbed and assimilated. The chemical formula and transpiration data alone afford no indication of the physiological importance of the substances; hence the nutritive value of these compounds should be estimated on the basis of the total water requirements of a plant during its period of growth and the ratio between carbon, nitrogen, and ash in the plant.

5. The phenomena of absorption and tolerance of plants in bogs deal plainly not with osmotic pressure relations so much as with considerations of the permeability of the absorbing protoplasmic membrane, its power of endurance, and its ability by enzymic action either to absorb and assimilate or to transform injurious bodies into insoluble impermeable compounds.

6. The organic substances in peat soils, while inhibitory to agricultural plants, have little or no effect upon certain xerophytic plants. It is therefore concluded that they may be positive forces not only in producing the natural succession of vegetation in bogs but also in determining xeromorphy and the associated relation of the members within each group which best succeed upon peat deposits. These organic substances play the differentiating role and are a cause of the infertility of peat deposits even when the amount of air and water in the soil is abundant and the temperature and humidity conditions are favorable to growth.

It is needless to point out that these facts have an important bearing on the agricultural exploitation of peat deposits and on the subject of the proper value of peat land for agriculture. It can be fully discussed only after a great number of practical experiments have been made under a wide range of exhaustive and careful study by trained specialists.

CHAPTER X

THE BACTERIAL FLORA AS A FACTOR IN PEAT FORMATION[1]

Historical Considerations.—The splendid contributions concerning the general relationship existing between soil microörganisms and scientific agriculture are their own testimony as to the soundness of the modern view of soil productivity. Of these contributions the subject of nitrification is one which has received the larger share of attention from scientific men, and the literature thereon is indeed voluminous. The value of nitrogen fixation by bacteria living within the soil itself and by bacteria which develop nodules upon the roots of leguminous and other plants, and the consequent increase in fertility of abandoned fields is a fact with which every student of agriculture has become familiar. A rôle less generally understood or appreciated is that of microörganisms in rendering a field or a habitat injurious to agricultural crops. The microörganic life in soils and the relationship of species as foes to the crop-producing capacity of soils is a line of research still before us. It is one which offers splendid opportunities for the collection of facts of great moment to the practice of agriculture, particularly in relation to the much debated question of fertilizers. It will enable a better economic utilization and conservation of soil resources.

The number of species concerned is exceedingly great. Some are dependent upon the presence of free oxygen, that is, they are aerobic; while others are anaerobic—air is not necessary for them to disintegrate organic material. There are present not only beneficial nitrifying bacteria upon which the formation of important and valuable chemical compounds in the soil depends, but also denitrifying, putrefactive, and pathogenic bacteria to which most of the injurious action of the soil and the diseases of the soil may be attributed. The problem concerning the processes and the products of the activity of harmful bacteria, and the correlated question of their intimate bearing upon a decreased fertility in soils have unfortunately been limited to work of a comparatively small number of investigators. A glance through the literature of soil bacteriology reveals that scarcely anything has been published on the physiological effects of injurious bacterial decomposition products upon agricultural plants.

Present writers seem to hold the view that among the simplest fungi, the *Schizomycetes*, few are present in peat bogs, and that only a

[1]The larger part of this chapter appeared in the Botanical Gazette, Vol. XLIX, 1910, pp. 330-332, Vol. LII, 1911, pp. 15-21, and the Ohio Naturalist, Vol. X, 1910, pp. 137-145.

small nnmber of species, included in perhaps only one family, are at all injurious to higher plants. Very little has been done thus far upon the problem of the bacterial flora in connection with the formation of peat, or in relation to the rotation of the plant associations from which it is derived and those that are cultivated upon deposits of this material. It would seem that investigations in this field would have been active as well as adequately represented, since peat does not lack appropriate vegetable matter as a source of food to the microörganisms. A peat deposit should, therefore, abound in disintegration products bearing a close relation to the physiological and structural features of growing plants.

That bacteria must have existed contemporaneously with the oldest vegetation is a natural supposition, and it is by no means unlikely, as Renault[1] has suggested, that the tissues of stem fragments in the ancient marshes were gradually broken down by bacterial action. Van Tieghem[2] drew attention as early as 1875 to the methods of operation of bacteria as destructive agents in the decay of plant débris in water. He was able to follow the gradual disorganization of the tissues and the various steps in butyric fermentation effected by organisms. This decomposition could go on not only in shallow water but also at a pressure of several hundred atmospheres corresponding to a great depth of water.

The presence of bacteria in peat soils has been established by Adametz,[3] Sitensky,[4] Wollny[5] and others. A brief study of the bacteria of some typical Iowa peat soils has been made by Pammel[6] who found that several organisms which were obtained as pure cultures reduced nitrates to nitrites. Ternetz[7] has isolated endophytic mycorhizal fungi from a number of ericads growing in bogs. These fungi are believed to have a capacity for nitrogen fixation. More recently Spratt[8] succeeded in demonstrating that the root tubercles of *Alnus*, like those of leguminous plants, assist in the assimilation of atmospheric nitrogen. And yet, the rôle which bacteria and fungi play in the transformation of plant tissue into peat, has been ignored or doubted by most investigators of peat, while others

[1]Renault, B., Sur quelques bacteriacees des temps primaires. Soc. Hist. Nat. d'Autun. 1895.

———, Recherches sur les bacteriacees fossiles. Ann. Sci. Nat., Vol. II, 1906.

[2]Van Tieghem, P., Sur le Bacillus amylobacter et son roled ans le putrefaction des tissues vegetaux. Bull. Soc. Bot., Vol. XXIV, 1877, p. 182.

[3]Adametz, L., Untersuchungen über die niederen Pilze der Ackerkrume. Leipzig. 1886.

[4]Sitensky, F., Über die Torfmoore Böhmens. Archiv der naturwissenschaftlichen Landesdurchforschung von Böhmen. Prag. 1891.

[5]Wollny, E., Die Zersetzung der organischen Stoffe und Humus bildungen mit Rücksicht auf die Bodenkultur. Heidelberg. 1897.

[6]Pammel, L. H., A comparative study of the vegetation of swamp, clay and sandstone areas. Davenport Acad. of Science, Vol. X, 1907, pp. 67-68.

[7]Ternetz, C., Über die Assimilation des atmosphärischen Stickstoffes durch Pilze. Jahrbücher f. wiss. Botanik, Vol. XLIV, 1907, pp. 353-408.

[8]Spratt, E. R., The morphology of root tubercles of Alnus and Elæagnus, and the polymorphism of the organism causing their formation. Annals of Botany, Vol. XXVI, 1912, pp. 119-128.

regard the bacterial influences as very small.[1] In almost no case were studies carried on to obtain more specific information both as regards the function and value of bacteria in the formation of peat, the reactions of the bacterial products upon higher plants and their rôle in the obvious distinction between successions of bog vegetation.

The writer's investigations have brought out the fact that peat soils contain unsuspected groups of bacteria which vary in number and efficiency during the seasons and with the several plant associations on a peat deposit. In the course of a study on the ecology of Cranberry Island, at Buckeye Lake, an examination of bog water and peat disclosed the fact that plants such as wheat, corn, beans and various other cultivated varieties which were grown on Cranberry Island for experimental purposes, showed marked difficulty of absorption; they soon became stunted, took on xeromorphic characters and in most cases died (Figs. 16-21).

Work of an experimental nature with cultures of bog bacteria made it evident that the injurious products of the bacterial bog flora accumulating in definite layers of the peat substratum were the leading factors to be considered in the physiological aridity of the local study. The observation was made that a sample of bog water in a well corked glass jar, when kept in the dark at 68°-77° F. (20°-25° C.), soon shows the formation of methane and other gases, and that in a few weeks a thin surface layer becomes noticeable made up of bacteria imbedded in a matrix. Exclusion of air prevents further growth of aerobes, for in flasks with narrow necks and closed with a paraffined cotton plug a surface growth is never evident. The breaking down of organic matter by bacteria seems to involve, therefore, not only the growth and multiplication of the agents of decomposition, but also an accumulation of by-products which soon decreases the rapidity of aerobic bacterial action.

Through the courtesy of Professor Morrey of the Bacteriological Department of the Ohio State University, and under his direction, the preliminary bacterial examination was repeated. Facts to justify the position as to the presence of a constituent that imparts an antiseptic action to bog water and bog soil are still lacking, but there is sufficient experimental evidence to justify the statement that the bacterial flora has the greater share, not only in the formation of these toxins, but also in the slow and partial decay of bog and swamp plants, that is, in the formation and preservation of peat. Experiments are now in progress to show that bacterial decomposition continues in water and at great depths, and that it is not prevented by the pressure of the overlying thickness of peat material or the depth of water.

Action of Bacteria in the Formation of Peat.—As a means of differentiation between the bacterial flora of the plant associations,

[1]Früh, J., und Schröter, C., Die Moore der Schweiz. Bern. 1904.

studies were made on the action of the bacteria in 0.5 cc. of bog water upon various culture media in fermentation tubes. Samples of water were collected in sterilized glass-stoppered bottles from each of the following stations: Station I, lake water; station II, marginal zone (*Decodon-Typa Hibiscus*); station III, cranberry-sphagnum zone, 1 to 3 feet below the surface vegetation; station IV, same, 3 to 5 feet below the surface level; station V, maple-alder zone, 1 to 3 feet below surface vegetation; station VI, same, 3- to 5-foot level; station VII, tamarack soil from Edgerton, Ohio; station VIII, peat soil under cultivation from Orrville, Ohio; station IX, peat soil under cultivation, reported as unproductive and "sterile," from Lodi, Ohio; station X, humus soil from the university woodlot (beech-oak-maple-elm). The culture media employed for this work were a 1 per cent. starch-peptone-water solution; 1 per cent. solutions of eane sugar, dextrose, and lactose in beef broth; plain bouillon; plain and litmus milk; 0.2 per cent. nitrate-peptone-water; Dunham's peptone solution for the indole test; nutrient gelatin and agar. Only the generally well known determinations, as of the breaking up of carbon and nitrogen compounds and the proportion of the various gases evolved, have been made. The chemical analysis of several of the soil samples of stations I to IX is given in tables 26, 29, 30 and 32.

The culture studies gave the following characteristic results after incubation for 5 days at 100° F. (38° C.). The action of the bacteria on starch shows in several stations the production of a ferment by the cultures. The starch is changed into a sugar which reacts with the Fehling test. Bacteria from stations III and IX show no action; in stations II and X the conversion is carried on a little way and then stops, there being always a red or purple reaction with iodine; in station I the starch conversion is almost complete; while in stations IV, V, VI, and VII certain putrid by-products inhibit in various degrees further conversion. Upon the addition of a few drops of potassium iodide, the blue color disappears rapidly in stations III, IV, and VI, the hydrated (?) iodine is deposited as metallic iodine upon the walls of the test tube above the solution. Reducing action is less active in stations V, VII, and IX. No decolorization occurs in stations I, II, and X. The accumulation of iodine is very strong in the test tube of station X and is very likely an indication of the presence of oxidizing ferments. With methylene blue the reducing action is the same in degree, respectively, in all cases running parallel with the iodine action.

In all stations, with the exception of station I, the action of the bacteria on saccharose shows both the conversion of the carbohydrate into glucose by the inverting ferment, and the production of gas and acid. The reaction is strongest in stations VIII and X; relatively small in stations V and IX; very little gas is evolved in station II. The gas is largely hydrogen gas and CO_2; the latter, with the exception of stations

V and VIII, is present usually in small quantities and was distinguished from other gases by its absorption in sodium hydroxide. Fermentation action is shown better on dextrose and lactose. There is little growth and gas formation in station I; no acid is produced in stations VII and IX; and very little hydrogen gas is formed in station VIII. In all cases the growth of the organisms produces a marked and varied pigmentation in the solutions.

In plain milk, rapid coagulation precedes further bacterial action in all cases except station IX, in which coagulation occurs very slowly. Milk is slowly peptonized anaerobically in stations IV, V, and VI; surface digestion takes place in stations III, VIII, IX, and X; it is rapid in stations I, III, and VI; and gas is produced in moderate quantities in all stations except station VIII. Litmus milk is coagulated in all stations; the medium gradually decolorizes and the cultures become acid in various degrees; the color does not return upon steaming the test tubes. With a majority, gas is produced in various amounts during digestion, except in station IX, in which the bacterial reaction is faint though strongly odorous.

On bouillon bacterial growth is slow; it is never very turbid or heavily clouded, and only in one case, station IX, gives a whitish precipitate.

The power of indole production is greatest with the organisms in stations III, V, and IX; the action is relatively small in stations II, IV, VI, and VII; and present to a feeble extent only in stations I, VIII, and X when tested with 0.02 per cent. solution of potassium nitrite and sulphuric acid.

The ability to form nitrites from nitrates in nitrate broth is common to the organisms in all stations. The amount of nitrites formed is high in stations IV, VI, IX, and X, and very small in stations I, II, VII, and VIII. The power to reduce nitrates to nitrites is not present in the same degree as noted above for the reducing action in starch media. It is certain that the microörganisms are capable of reducing nitrates, but to some extent metabolic products, apparently, modify the action. The test was made with equal parts of sulphanilic acid and naphthylamine solution.

The presence of ammonia was tested with Nessler's reagent. The reaction is stronger in stations VII and X than in any other. A faint test is obtained in station IX. Nitrogen gas is produced from nitrates in stations VII and VIII.

In view of the above experiments it is clear that the processes in peat formation involve both aerobic and anaerobic organisms, and result in organic decomposition products of different chemical and physical properties.

In the upper layers of the peat substratum, and always in close contact with the oxygen of the air, the first of the processes takes place.

The starch, sugar and protein in the tissues of dead plants are converted by certain peat bacteria and fungi into substances which involve the addition of oxygen. That oxygen plays the important rôle other writers demonstrated both by experiment and the analysis of the gaseous and other products. The carbohydrates by this means may be broken down to CO_2 and H_2O and the nitrogenous substances to NH_3, HNO_3, and possibly free nitrogen. Ammonia may be changed further to a nitrite or a nitrate. An acid condition usually hinders and a slight alkalinity favors these activities. Similarly the air-dry condition of the soil from lack of water, or saturation of it with water influences unfavorably the biological relationships, for the process is essentially one aided by a free access to air. If aeration is continued it would result in the complete destruction of the vegetable material. The formation of ordinary humus upon peat deposits which have been cleared and ditched or cultivated may be cited as an example.

That the peat substratum is the seat of other activities and is of as much importance to growing plants as the one just described is proven by the presence of reducing substances. The disintegration of vegetable material, which occurs in the upper layers of the organic soil, is rarely a continuous and successive change to products of simpler compounds. Various putrefaction bacteria also perform their rôle during the oxidation process. The organisms are aerobes as well as facultative anaerobes. A number of transition products arise, which do not furnish a suitable food material for similar or other forms of bacteria and fungi. The accumulation of their own by-products makes the debris unfavorable for the continued existence of the organisms involved in their production; the substances being toxic, paralyze and further impede the growth of bacteria. Depending upon and varying with the stage in the progress of decay, is the degree of toxicity and the reducing action of the medium. At a depth of even a few inches below the surface the rate of oxygen diffusion is small as compared with the demand for it. With the gradual increase and accumulation of these unoxidized substances the work of disintegration decreases and the resistant plant tissue is broken down less rapidly. The process is essentially one of fermentation and reduction. Carbon dioxide is also the principal gaseous product, but its relative amount is greatly reduced. Methane (CH_4) and other gases result from the decomposition of lignocellulose substances; and the proteins are broken up into amino acids, indole and other nitrogenous compounds very little known. The secondary products are very numerous. They are of widely varying composition and structure, as well as physical and chemical properties. The final products of decay are very different under the different conditions of temperature and soil, the amount of air it contains and the amount of water. Only as conditions arise which favor the removal of these products of partial decomposition can disintegration continue.[1]

Reactions of Bacterial Products Upon Higher Plants. — The facts brought out in the culture studies do not show, however, the species of microörganisms, nor the reaction between them and the growing plants. A knowledge of the morphology of the simple form of organisms does not suffice to differentiate the numberless more or less similar species. It is difficult and almost impossible to identify a distinct and constant type for each species, or recognize form-differences suitable for classification. A detailed analysis of the bacterial content of a virgin forest soil rich in humus has been given by Rivas,[2] but it does not seem that culture methods, heretofore in use, have made possible systematic grouping, or the variety of tests needed for accurate and trustworthy comparisons. No necessity exists for doubting the value of cultural characters; it is merely maintained here that additional and new methods must be tried, and tests should be scrutinized from every standpoint. Though widely different in their behavior in culture media and in their relation to air, yet the injurious action of the bacterial flora from the different bog-plant associations and societies should be ascertained within the limits of their natural habitat, and should be determined also with reference especially to the degree of functional inhibition on higher plants. It is not until a study is made of the special reaction of bacterial transformation products in sterilized bog water upon the growth of agricultural plants that the lack of correspondence in salient features between habitat relations and physico-chemical reactions in artificial media becomes noticeable. Considerable difficulty was experienced in the isolation of organisms with the conventional media. In the majority of cases very little growth was obtained on beef broth, gelatin or agar. Gelatin and agar media made with peat and bog plant juices proved more satisfactory for isolation purposes. Moreover, bacteria of rapid growth and early appearance of colonies on the artificial media caused less retardation on the growth and transpiration of wheat plants when inoculated into sterilized bog water than bacteria of slow growth. In some cases the isolated pure cultures made little headway on beef broth or peat agar media after a period of 3-5 months, but gave strong inhibition in the growth of wheat plants within 3 weeks after inoculation into sterilized bog water from their respective plant zones.

Their own by-products in artificial culture media apparently cause the death of a large proportion of the organisms, inhibit the growth and thus paralyze the remainder. Possibly the need of a special

[1]Greater aeration, cultivation, better drainage relative to the ground-water level, liming or composting with manure to further a more associative action among the bacterial organisms present, serve as remedies, and effect a notable improvement in fertility.

[2]Rivas, D., Bacteria and other fungi in relation to the soil. Contributions from the Botanical Laboratory of the University of Pennsylvania, Vol. III, 1910, pp. 243-274.

technique of isolation or of specific culture media accounts for the negative results which many observers experienced in the cultivation and isolation of peat bog bacteria. It is reasonable to assume, therefore, that the lack of uniformity in results implies both obligate symbiosis and the need of a physiologically balanced culture medium. The fact that the organisms are obligate saprophytes, capable of growing only on substrata similar in composition to the character of the surface vegetation, is indicative of a close interdependence; their rapid growth in a medium in which cellulose and lignin compounds predominate suggests a specific cytohydrolytic action.

Certain microörganisms in station III have been found to possess the ability to dissolve filter paper. The bacteria were in Omelianski's culture, but destroyed cellulose under aerobic conditions. Kellerman and his associates[1] have recently announced the isolation of several species of cellulose-destroying organisms. Most of the species were found to grow readily upon media such as beef agar, gelatin, starch and potato. Some are facultatively anaerobic but none are strictly so. The reaction between them and growing plants has not been determined.

An attempt has been made to study the physiological reaction of the products formed from the activity of single isolated species, as well as the effects of the residual products due to mixtures of bog bacteria. Without going into too much detail it is sufficient to point out here the following:

From a fresh sample of bog water and bog soil dilution cultures were prepared. The isolation of the various species was continued upon peat-agar plates, and later in test tubes containing a beef-broth-agar medium, until from the bacterial colonies which appeared upon them pure cultures were obtained. About 35 different species of bacteria have thus far been isolated. The organisms belong for the most part to the aerobes. Of the bacteria thus isolated, 21 species were tested for their toxin-producing power upon a sterilized solution of bog water and peat. A number of flasks of a liter capacity, containing the sterilized solution, were inoculated with the respective pure cultures. Several flasks were left sterile to serve as controls, while others were inoculated with 1 cc. of fresh bog water. An additional test condition was arranged at the same time from the normal untreated bog water. All flasks were then placed in an incubator at 100° F. (38° C.) for a period varying from two, four to six weeks, and at such times were then brought to the laboratory. All physiological experiments were made in duplicate series and the greatest caution was observed to reduce the dangers of contamination during the preparation of the cultures. The physiological tests were made in half-liter Mason jars covered with black paper and containing 500cc. of the inoculated solution. Wheat seedlings

[1]Kellerman, K. F., McBeth, I. G., and Scales, F. M., Fermentation of cellulose. Abstract in Science, Vol. XXXV, 1912, p. 199.

were used for these cultures. The seeds were germinated in sterilized quartz sand until 4-5 cm. high.* They were then carefully washed in distilled water and transplanted to the cultures. Six seedlings were used in every experiment. The seedlings were individuals selected out of a large number of plants. The flat corks to which they were fastened were previously sterilized and paraffined. The cultures were then placed in the University greenhouse in situations where conditions of temperature and diffused light were uniform. In connection with temperature and humidity readings the measurement of the evaporating power of the air was obtained, a standardized porous cup atmometer being used for this purpose. The growth of the plants in the various cultures was measured by transpiration relative to the control cultures; the water loss was recorded every fifth day by weighing the cultures. In all cases the experiments were extended for fifteen days. From the data at hand the following have been selected to illustrate the variation in virulency of bacterial products (tables 20 and 21).

TABLE 20

TRANSPIRATION DATA FOR SOLUTIONS INOCULATED WITH PURE CULTURES OF BOG BACTERIA

Series III	Bacteria	Transpiration in grams				Comparative transpiration	Percentage of decrease
		5th day	10th day	15th day	Total		
	Control	9.33	42.92	66.85	119.10	100	0
	B. 20	8.85	41.30	44.06	94.21	79.10	20.90
	B. 22	8.30	38.15	42.90	89.35	75.02	24.98
	B. 7	8.55	31.80	42.80	83.15	69.81	30.19
	C. 3	7.15	30.90	43.95	82.00	68.85	31.15
	C. 4	7.60	29.70	44.40	81.70	68.59	31.41
Duplicate series ___	Control ___	8.80	44.50	66.83	120.13	100	0
	B. 20	8.40	34.25	45.98	88.63	73.77	26.23
	B. 22	7.05	35.40	46.10	88.55	73.71	26.29
	B. 7	8.15	34.45	42.21	84.81	70.59	29.41
	C. 3	8.10	30.90	44.25	83.25	69.30	30.70
	C. 4	8.40	31.15	41.65	81.20	67.59	32.41
Atmometer		102 gr.	136 gr.	125 gr.			

*The following method, used by the writer for some time, is found to be convenient and very valuable for sprouting wheat seeds. An enameled dish, 20 cm. in diameter and 8 cm. high, the bottom of which is perforated with openings of 2 mm. is filled with sterilized quartz sand. To keep the quartz from falling through the dish is lined with filter paper, or the openings are decreased to a size allowing the needed contact with the water by repeated dipping of the dish in melted paraffin. The dish is placed upon cork supports in a large enameled iron pan, 25 x 10 cm., containing water up to the lower 2 cm. of the dish. To prevent injury to the seedlings from the accumulation of materials which the seeds exude during germination the water is changed daily. The germinator is covered with a glass-stoppered bell-jar whose stopper may readily be replaced by one of rubber with one or more holes. When the plants are of the desired height the pan is filled with water, thus allowing a ready removal.

TABLE 21

TRANSPIRATION DATA FOR SOLUTIONS INOCULATED WITH PURE CULTURES OF BOG BACTERIA

Series VII	Bacteria	Transpiration in grams				Comparative transpiration	Percentage of decrease
		5th day	10th day	15th day	Total		
	Control	17.65	36.20	36.60	90.45	100	0
	Bog water	7.65	11.30	8.90	27.85	30.79	69.21
	B. 25	18.15	29.30	26.85	74.30	82.14	17.86
	Bg. w. 1cc	18.27	30.15	25.70	74.12	81.94	18.06
	B. 13	15.72	24.65	30.85	71.22	78.74	21.26
	B. 2	17.45	29.05	24.30	70.80	78.27	21.73
	B. 1	16.60	28.95	24.85	70.40	77.83	22.17
	B. 27	12.60	24.90	22.80	60.50	66.66	33.34
	B. 6	14.00	25.40	20.80	60.20	66.55	33.45
	B. 4	14.95	23.80	20.45	59.20	65.46	34.54
	B. 29	11.60	15.55	15.85	43.00	47.54	55.46
Atmometer		114 gr.	117 gr.	102 gr.			

Using the transpiration of the controls as a basis and representing it as unity (100) the different bacterial cultures have values in the order as indicated in the last two columns of the table. These figures show conclusively that in all cases the bacteria are responsible for the proportionally diminished transpiration and growth. The transpiration values fluctuate to a considerable extent; in some cases the differences from the controls are not so very great, but in all cultures the values lie below that of the control. The plants function less readily and their rate of reaction diminishes as the active bacterial products increase in amount.

The evidence derived from the duplicate series is omitted, showing as it does, results as closely parallel as those in table 20. To what extent the tables suggest a possibility that bacterial action when correlated with physiological criteria may determine the crop-producing power of different soils need not be discussed at length. The figures speak for themselves. Several facts, however, seem to be clearly brought out in the above data. The transpiration figures of the first five days in B. 25 and B. 1 cc. indicate that the growth of the plants was considerably stimulated by the presence of the toxic substances in the solution. Those of the last five days prove that the solution was decidedly injurious. B. 13 is worthy of note since the plants in that solution disclose a gradually intensified power of resistance and a physiological phase marked by a greater functional activity. The maximum rate of transpiration occurred on the fifteenth day as in the control, while that of all remaining cultures appeared on the tenth day. As compared with the control the inoculated cultures, it will be observed, have reduced the transpiration quantity of wheat plants 20 to 52 per cent. Another matter is the degree in which individual plants vary in tolerance and resistance. When the bacteria are omitted from the sterilized solution no evidence of toxicity is noticeable for the wheat plants growing in the solution, and their variability in growth, and green and dry weight, deviates but little from the common norm. But when inoculated the culture medium becomes a condition always active in stimulating or depressing normal functions. The task of securing a coördination between functions of absorption, transport and transpiration, becomes a very complicated one for the plants, varying greatly within the same species and with different species. The analysis of these experiments has strengthened the conviction that the best functioning plants rather than the general average represent the proper test of the possibilities of agricultural plants under the given conditions, and that adjustment to conditions is a more noteworthy characteristic than structural deviations or acclimatization. Much economic value would attach to an extension of these experiments by determining through selection and a more detailed physiological study the cultivated forms resistant and immune to the effects of this type of soil bacteria, and the nature of the resistance.

Additional evidence of a similar nature and derived from experiments of more recent date is given in table 22. The data confirm the earlier tests and also demonstrate the ability of some mycelial bog fungi and the organisms in alder tubercles[1] to increase transpiration and the amount of assimilable compounds, and, hence the green weight of wheat plants considerably above that of plants in untreated bog water. Normal appearance is here associated with a uniformly higher absorption of the solution, a greater amount of transpiration and green weight produced, and with the healthy condition of roots and leaves. The wheat plants in the cultures had the usual osmotic pressure isotonic with about a 0.2 to 0.3 normal potassium nitrate solution. Difficulty in absorption (and tolerance of toxic substances) does not seem to be correlated with high osmotic pressure, as is known to be the case with plants in desert areas.[2] The systematic position of the organisms has not been determined with certainty. The fungi seem largely species of molds such as *Penicillium*, *Fusarium* and *Aspergillus*.

In order to determine the ability of the microörganisms to convert soluble proteins into amino acids and allied products of the disintegration of proteins, enough peptone was added to sterilized solutions to make an equivalent of a 1 per cent. peptone culture. After sterilization the solutions were inoculated with the bacteria indicated in table 23. The cultures were tested physiologically at the end of a two-week

[1]Spratt, E. R., The morphology of the root tubercles of Alnus and Elæagnus, and the polymorphism of the organism causing their formation. Annals of Botany, Vol. XXVI, 1912, pp. 119-128.

[2]Fitting, H., Die Wasserversorgung und die osmotischen Druckverhältnisse der Wüstenpflanzen. Zeitschr. f. Botanik, Vol. III, 1911, pp. 209-275.

TABLE 22

TRANSPIRATION DATA OF WHEAT PLANTS IN SOLUTION OF STERILIZED BOG WATER AND PEAT, INOCULATED WITH BOG BACTERIA, MARCH 31-APRIL 15, 1910

Culture	Transpiration in grams	Green weight produced	Water required for 1 gram of green matter
1. C. 19 b & f	8.90	0.80	11.12
2. C. 15	12.00	1.16	10.37
3. D. 20	14.90	1.14	13.07
4. C. 13	13.08	0.94	13.91
5. C. 7	15.65	0.98	15.96
6. C. 16	15.25	0.93	16.39
7. C. 19 (fungus)	17.93	1.60	11.20
8. C. 17 (fungus	17.40	0.01	17.22
9. C. 9	18.07	1.06	17.04
10. C. 21 (fungus)	27.33	2.36	11.58
11. Alder tubercles	50.31	2.20	22.86
12. Mixed culture of above	67.48	1.92	35.14

Atmometer: 11.7 cc. daily average.

incubation period. Since the danger of contamination in peptone cultures becomes increasingly greater, the transpiration figures for only the first five days are tabulated. The wheat plants had grown in each experiment for three days when they were photographed.

A brief inspection of the table and the photographs (Figs. 25 and 26) suffices to show that transpiration, growth, green and dry weight of plants are in this case proportionally reduced. The mixed culture solution (Bg. w. 1cc.) in which the percentage decrease in transpiration is as high as 90, seems to show that it is the function of some of the bacterial organisms to do the initial work of rendering soluble the protein compounds in a peat substratum. The process of denitrification is carried up to a point where the products become further decomposed by other organisms. A whole series of bacteria, therefore, seems to be involved, to which are due the residual products, the sum of which in

TABLE 23

TRANSPIRATION DATA FOR 1 PER CENT. PEPTONE CULTURE SOLUTIONS, INOCULATED WITH BOG BACTERIA

Series IX	No.	Bacteria	Transp. (5th day), in grams	Comparative transpiration	Percentage of decrease
	6	Control	17.65	100	0
	7	Peptone check	7.00	39.65	60.35
	13	B. 13	4.85	27.47	72.53
	14	B. 25	2.70	15.30	84.70
	11	B. 2	2.30	13.03	86.97
	12	B. 4	2.40	13.60	86.40
	15	Bg. w. 1cc	1.87	10.60	89.40

part constitutes the toxicity of the habitat encountered on Cranberry Island, the formation of methane gas, and the reactions which form the basis of the process of humification.

At the end of the experiment a chemical examination of these culture solutions indicated the presence of indole, ammonia, and various non-volatile products in various proportions. A marked difference was noted in the ability of the different species of bacteria to produce indole and ammonia. The highest quantity of ammonia was produced by B. 13; the least amount was recorded for Bg. w. 1 cc.—the culture solution, it will be remembered, which consisted of a mixture of the bacteria found in 1cc. of fresh bog water. None of these products were found

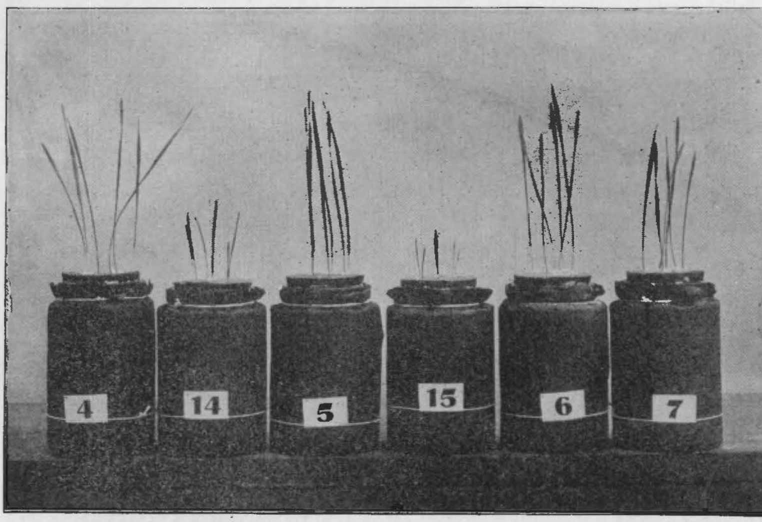


Fig. 25.—Wheat plants growing in 1 per cent. peptone bog water solutions inoculated with pure cultures of bog bacteria. Numbers correspond with data in Table 23.

in the control (sterilized bog water and peat). It is also to be noted that in the various pure bacterial cultures neither the organic acids nor the ammonia underwent a further change and that the absence of air is not a limiting essential condition for the growth of the bacterial organisms. The fact is interesting that the organisms belong for the most part to the aerobes.

In concluding this part of the discussion it is well to note the extent to which the results show clearly that the retardation in growth of wheat plants is not caused by physical-chemical conditions but through the direct activity of the bacterial flora. It has long been suspected that a reciprocal relation exists between groups of soil bacteria and the plants growing upon the soil. Various writers have been able to point out that marked differences in the productive power of different soils follow the growth of wild plants, and that these differences persist for some time. It is generally concluded, therefore, that the injury caused to cultivated plants by weeds or previous crops might be due to influences on the bacterial life in the soil, and in a direction unfavorable to succeeding agricultural crops. No doubt, the "exhaustion" of soils which is frequently met with, and which cannot always be attributed to the removal of plant nutrients, is, in part, an allied phenomenon. Whether or not a strong, intimate and controlling relation exists between soil bacteria and surface flora, and how the bacterial organisms affect the character, and the association and succession of plants cannot remain a matter of indifference to physiological ecologists. At best very little is known of this phase of the process, and of the reactions and effects of the bacterial products upon plant life.

There yet remains the question how far the microörganisms are active in the change of vegetable matter to peat and lignite, and in the formation of gases and of coal.[1] To what extent is the coöperation

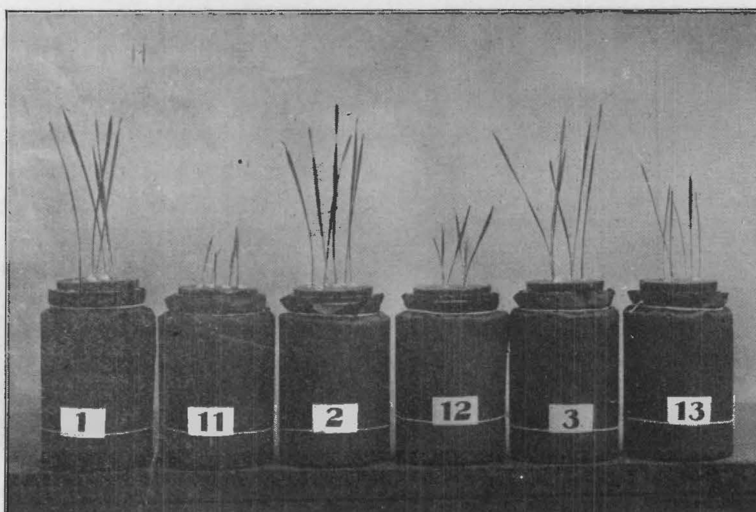


Fig. 26.—Wheat plants growing in 1 per cent. bog water solutions inoculated with pure cultures of bog bacteria. Numbers correspond with data in Table 23.

either essential, useful, or dangerous in the formation and character of organic compounds available for assimilation? What are the factors affecting and limiting the decomposition of organic matter? What is the nutritive value of the different carbon and nitrogen compounds arising through the activity of microörganisms? Toxic substances possess an unlike physiological value to different plants and hence it is but one step farther to raise the question of the comparative nutrient value of these organic compounds.[2] It has been fairly well demonstrated that plants other than the legumes possess structures with bacterial-like organisms in symbiotic association, which are capable

[1]An interesting theory by Dr. Charles B. Morrey, to account for the origin of oil and gas, is quoted in Bulletin 1, of the Geological Survey of Ohio, 1903, pp. 313-314.

[2]Haskins, H. D., The utilization of peat in agriculture. Massachusetts Station Rept. 1909, pt. 2, pp. 39-45.

Lipman, J. G., Report of the Soil Chemist and Bacteriologist of the New Jersey Agri. Exper. Sta., 1910, pp. 188-195.

of absorbing nitrogen from the air and transforming it into the organic state. Both the tissue and humus resulting from the decay of *Alnus* and its associated undergrowth are notably richer in nitrogen than in the organic material of the preceding cranberry-sphagnum association (table 33.) But the whole matter requires much further work before the correlation between the soil processes and the obvious differences in the plant associations displacing each other can be made clear.

It would be idle, also, to expect that the bacteriological data in themselves are sufficient for a clear interpretation of toxicity and physiological drought relations, or of sterility of soils. If attempted, the interpretation would be, indeed, one-sided; there is a coördination of factors, each and all of which exert a relatively marked influence. Temperature, water, and air conditions in the soil, as well as the physical and chemical character of it, and the surface vegetation play an important rôle in determining the character of the bacterial flora, and, therefore, also the character of the biochemical products formed. The bacteriological-chemical, as well as the physiological method deserves on that account a closer consideration. The determination of the transformation products in various media inoculated with bog bacteria should possess an exactness and a reliability that would make it suitable for the solution not only of agricultural but of ecological problems as well. It is hardly necessary to go into further detail. It is only too clear that the need for new investigations is pressing, and that especially new points of view and new lines of research are imperatively required.

Summary of Bacterial Relations to Peat Deposits.—With these suggestions in mind, the results on the bacterial reactions in culture media submitted above may now be summarized as follows:

Peat soils are very rich in bacteria inducing diastatic, inverting, proteolytic, cytohydrolytic, and reducing action.

The organisms vary in kind and number with the nature of the substratum.

The majority of the forms are found to thrive as saprophytes, digesting the debris in the upper layer of the peat substratum and aiding in a partial disintegration of the accumulating deposit. Many forms thriving as saprophytes among the indigenous flora give little aid in the elaboration of food materials to invading or introduced plants.

The organisms show associative relations and a marked interdependence between themselves; one set of bacteria prepares a medium for another out of an unfavorable substratum, and this paves the way for others to continue the destruction. Signs are not lacking, however, of relative indifference and even antagonism among the organisms, resulting in products which retard and inhibit further bacterial growth and disintegration processes.

A certain proportion of bacteria in these soils has the special ability to produce substances, perhaps unassimilable, certainly injurious to all but indigenous plants. In a peat substratum the percentage of bacteria aiding in the production of deleterious substances, such as reducing substances, gases, indole and other fermentation products, varies with the season of the year, but especially with the advance of the vegetation toward the closed deciduous forest association. These substances constitute the unsanitary conditions in soils, the negative factor which limits the rate at which the splitting up of organic compounds into ammonia and other assimilable substances proceeds. They are the characteristic symptoms of a diseased, sterile soil. The greater oxidation action in the productive peat soils is due to the activity of a different set of bacterial organisms. The rôle which microörganisms play in the soil, points, therefore, to the fact that among other things a considerable relation exists between the processes of disintegration of organic material and the succession of plant associations in bogs and marshes, and in peat soil under cultivation.

Each plant association has its own bacterial flora maintaining a physiologically balanced condition in the soil. The substratum is an ever varying medium, the seat of physical, chemical, and vital activities which directly and indirectly influence its relative fertility and the character of the surface vegetation.

Varying with the power of multiplication and metabolic activity is the quantity of the products of decomposition constituting a toxic, physiologically arid habitat at one phase, and an available supply of nutrients to plants at another stage of the process. Acidity, toxicity, and reducing action represent merely a stage in the decomposition of organic matter. In the natural successions which ensue, each plant association augments the efficiency of the soil as a habitat. The soil processes involved are an efficient natural process for the maintenance of relative productivity. Differences in the mineral components are trifling compared with the biological processes.

The formation of peat is accomplished mainly by the breaking down of carbon compounds, especially through fermentation action upon carbohydrates and ligno-cellulose of plant tissues with the production of marsh gas and reducing substances. This action must be carefully distinguished from the later stage which transforms peat into humus, and the organic matter into harmless and to some extent assimilable compounds. Some forms of nitrifying organisms in symbiotic relation with higher plants (*Alnus*) render the succession of vegetation more effective.

The sum total of the reactions in any stage of the process exercises a physiologically selective function upon invading plants, furthering the growth of such plants whose roots are not merely absorbing organs, and excluding and eliminating all others in which differential protoplasmic permeability and the power to make cellular and extracellular changes is inefficient.

The significance of the data calls, however, for still further experimentation to be of sufficient evidence to assume a specific metabolism in bog plants, or to disclose the chemical nature of bog toxins.

CHAPTER XI

THE CHEMICAL FEATURES OF PEAT DEPOSITS

General Consideration.—In the preceding chapters evidence has been cited relative to the origin and formation of peat deposits and the plants from which peat is derived. The vegetable origin of the material is clear and needs no further discussion, but its chemical constitution is very difficult to determine. The necessary investigations are not only difficult but the methods are not well formulated. The series of changes are plainly traceable from the living plant cover of a peat bed through the fibrous and matted material to the well decayed, structureless portions at the bottom or at the outer edge of the deposit, but in chemical constitution it is an indefinite combination of organic compounds. In addition, different deposits vary greatly in composition and in physical and chemical properties, thereby making it impossible to write chemical equations which would represent the various transformations. For fuel purposes this variability of peat is often unimportant, but not so when it is employed in other special, technical ways and for agricultural purposes.

Though the principal organic compounds from which the débris is derived are the carbohydrates and proteins produced by vegetation, there are formed in the course of the growth and reproduction of bog plants many other compounds, alkaloids, acids and complex compounds; and during the decomposition of these substances by bacteria and fungi, still other compounds and transition products arise in the form of gases such as marsh gas, hydrogen sulphide and carbon dioxide along with various water-soluble compounds and substances commonly spoken of as dehydration products of carbohydrates. For most of these the names and written reactions have little meaning as now understood. Early views regarded the various constituents as having the same general properties and relations to each other. Modern views present this problem as one of greater complexity. There have appeared several papers on methods of determination, on the nature of the organic nitrogenous compounds which result from decomposition with acid or alkali, on the variable character of the material, the solubility of humus and peaty substances in different solvents, the number of separated fractions and distillation by-products; but no one organic débris has been studied exhaustively as yet, nor has any attempt been made to determine and definitely to identify isolated compounds. It is only recently that this problem has been found to be susceptible of solution.[1] To make clear its chemical nature, to determine the different classes of compounds that can result from the decomposition of the organic material and to know the processes of decay more fully in relation to questions of humification and of soil fertility should be one of the leading problems of the Government Bureau and of the several State experiment stations.

Tables of Analyses of Peat Samples.—Aside from the more detailed and difficult studies on the chemistry of peat soils, there are certain broad distinctions and tests that form a reliable foundation upon which to base judgments. This is especially to be seen when the more completely decomposed peat is compared with the plant débris in its more nearly original state. The following series, in part by J. Websky,[2] is especially suggestive. The analyses are calculated on an ash-free basis, and show a progressive increase in carbon and a corresponding decrease in hydrogen and oxygen.

TABLE 24

ANALYSES OF VARIETIES OF PEAT

	Carbon	Hydrogen	Oxygen	Nitrogen
Sphagnum peat	49.88	6.54	42.42	1.16
Light-brown peat	50.86	5.80	42.57	0.77
Red-brown peat	53.51	5.90	-----	-----
Dark-brown peat	56.43	5.30	-----	-----
Blackish peat	59.70	5.70	33.04	1.56

For comparison with peat and other organic matter derived from plants, such as wood and coal, the following table 25 has been taken from determinations cited by Clarke.[3]

The table restates in a similar form the steady decrease in oxygen and hydrogen, and the fact that the loss in the former is proportionally greater than that of the latter element. There is also an indication of the changes which peat must undergo in a possible conversion to coal and of the theoretical heating value per pound in British thermal units.

[1]Schreiner, O., and Schorey, E. C., Chemical nature of soil organic matter. U. S. Dept. of Agriculture, Bureau of Soils, Bull. 74, 1910.
Jodidi, S. L., Organic nitrogenous compounds in peat soils. Michigan Agri. Exper. Sta., Technical Bull. 4, 1909.
Robinson, S. C., Organic nitrogenous compounds in peat soils, II. Mich. Agri. Exper. Sta., Technical Bull. 7, 1911.
[2]Jour. prakt. Chemie., Vol. XCII, 1864, p. 65.
[3]Clarke, F. W., The Data of Geochemistry, 1908, p. 658.

TABLE 25

AVERAGE COMPOSITION OF ORGANIC MATERIALS AND CALORIFIC VALUES

	Carbon	Hydrogen	Oxygen	Nitrogen	Calorific value B. t. u.
Wood	49.65	6.23	42.20	0.92	5760.
Peat	55.44	6.28	35.56	1.72	8600.
Lignite	72.95	5.24	20.50	1.31	(?)9000.
Bituminous coal	84.24	5.55	8.69	1.52	11,000.
Anthracite	93.50	2.81	2.72	0.97	14,600.

For economic purposes, the most important facts in peat and other organic matter of vegetable origin are those which deal with the fuel value; that is, the amount of volatile matter and non-combustible products formed during the process of burning. The characteristics which determine fuel value will be indicated in part in a later paragraph (pp. 374-377); the most important are water content and ash, lowering the heating value nearly in proportion to the amounts in which they are present.

Freshly dug peat from an undrained deposit consists of from 80 to 95 per cent. of water. The weight of a cubic foot may be as much as 75 pounds. After a few days of exposure to the air the water content will be reduced by at least one-half its original amount. Continued drying in the sun and wind finally lowers it from 8 to 25 per cent. with a shrinkage involved to one-fourth of its original volume. The water content of air-dried peat varies according to season and variations in relative humidity of the air. The weight of water that must be evaporated from a ton of wet material, as its water content is lowered by 10 per cent. stages to the air-dried product, appears on p. 170. The seriousness of the problem involved and the financial impracticability of drying peat by artificial heat are easily recognized. In preparing to exploit peat deposits the simplest equipment is the one most likely to give satisfactory returns in fuel. Every added process of treatment adds to the cost of the product and decreases the profit.

The weight of a cubic foot of air-dried cut peat ranges from about 10 pounds for very light, fibrous kinds to over 60 pounds for the black, disintegrated variety. The lighter, more fibrous kinds of peat ignite when heated in the air at about 400° F. (200° C). Black and denser varieties do not ignite as readily and often need a higher temperature to induce combustion. The maximum temperature developed by thoroughly dried peat of good quality is over 4000° F. (2,200° C.). This temperature is, of course, lowered by the presence of small amounts of water or ash and is increased by artificially heating or drying the peat, thereby increasing the proportion of carbon relative to the volatile matter present. The theoretical heating value is, however, practically the same whether the peat is cut, pressed, dried by steam heat, or briquetted in several commercial ways. On account of the distinctions and to secure uniformity of statement in comparing fuel values, the chemical analyses are reported here (table 26) in the form commonly accepted. The analytical methods are those for coal analysis as adopted by a committee of the American Chemical Society and need not be discussed here.

In table 26 the results of the analyses of Ohio peat are given by counties alphabetically arranged. The table shows the locality by county, township and section, acreage, the maximum depth of peat found in each deposit, its character, the field and laboratory number assigned to each sample, and the chemical analysis. The samples as received at the laboratory contained varying amounts of moisture; hence the moisture percentage is taken from air-dried samples. The chemical analyses were made upon the samples after all the water was eliminated by heating to constant weight. The determinations include the volatile combustible matter, fixed carbon, ash, nitrogen, sulphur, in a few cases iron, and the fuel value in British thermal units. The samples of peat were collected by the writer in 1909-1911. They were analyzed in the peat laboratory of the United States Bureau of Mines at Pittsburgh, under the direction of Mr. A. C. Fieldner.

The table (26) shows that in 64 per cent. of the determinations the thermal value lies between 8,000 and 8,900 British thermal units and that 36 per cent. fall below 8,000. In almost all samples below a calorific value of 8,000 B. t. u., high ash content is the more important defect, as is seen by comparison with Figure 29 on page 377. The review of the analytical results seems to indicate that the various deposits are tolerably constant in particular locations, but that they change somewhat from one portion of the State to another. There is sufficient correspondence to warrant the application of the analyses here published with reasonable confidence in estimating the quality of peat in the neighborhood of the locality from which the samples were taken.

TABLE 26—LOCATION, DESCRIPTION AND ANALYSES OF OHIO PEAT

No.	County.	Township	Section	Acreage	Depth in feet	Character of peat and vegetation
1	Ashland	Lake	23	60	17	Reddish brown, fibrous; cranberry-spahgnum meadow.
2	Ashtabula	Orwell	----	1,000	5	Dark-brown, partly fibrous, woody and well decayed. Tamarack, maple, alder.
3	Champaign	Urbana	31-32	600	4	Dark-brown, slightly fibrous, well decayed. Cedar.
4	Columbiana	Center	7- 8	200	6	Dark-brown, well decayed, partly fibrous. Marsh and tamarack.
5	Crawford	Auburn	----	500	5	Dark-brown, partly fibrous. Under cultivation.
6	"	Cranberry	24-26	300	6	Same.
7	Cuyahoga	Solon	----	300-400	10	Brown, well decomposed, partly fibrous. Sedges and others.
8	Darke	Butler	7, 18	200 (?)	2	Dark-brown, well decayed. Under cultivation.
9	"	Harrison	13	----	4	Same, slightly fibrous.
10	Defiance	Milford	2-11	100	15	Dark-brown, well decayed, slightly fibrous. Tamarack.
11	"	"	----	5	15	Brown, fibrous, partly structureless. Under cultivation.
12	Fairfield	Amanda	26	----	12	Dark-brown, well decayed, partly fibrous. Under cultivation.
13	Geauga	Bainbridge	----	70	19	Brown, partly fibrous, well decayed, with several bog associations.
14	"	Burton	----	100	17	Same, slightly woody.
15	Greene	Bath	1- 2	100 (?)	7	Dark-brown, partly fibrous. Under cultivation.
16	Hancock	Big Lick	20-34	2,000	3	Dark-brown, partly structureless, somewhat woody. Heath bog.
17	Hardin	Marion	27	16,000	5	Dark-brown, partly fibrous, well decomposed. Under cultivation.
18	"	"	27	----	5	Dark-brown, well decomposed. Maple.
19	Holmes	Washington	26	2	19	Brown, fibrous, well decomposed below. Cranberry-sphagnum.
20	Huron	Richmond	----	5,500	15	Dark-brown, partly well decomposed. Bog meadow and shrubs.

TABLE 26—LOCATION, DESCRIPTION AND ANALYSES OF OHIO PEAT

No.	County.	Township	Section	Acreage	Depth in feet	Character of peat and vegetation
21	"	New Haven	----	3,500	9	Dark-brown, well decomposed. Under cultivation.
22	Licking	Licking	----	4,000	30	Dark-brown to black, partly fibrous.
23	"	"	----	----	30	Dark-brown, well decomposed, partly fibrous. Maple-alder thicket.
24	"	"	----	----	30	Brown, coarsely fibrous. Cranberry-sphagnum meadow.
25	Mahoning	Beaver	24–36	500	16	Dark-brown, well decomposed, partly fibrous. Tamarack.
26	Medina	Harrisville	----	2,000	5	Dark-brown, partly fibrous. Under cultivation.
27	"	Westfield	----	----	8	Fibrous, partly well decomposed. Sterile soil.
28	Mercer	Granville	----	1,000	7	Dark-brown, structureless, slightly fibrous. Under cultivation.
29	"	"	----	----	4	Same.
30	"	"	35	----	1– 2	Same.
31	Montgomery	German	18	----	4	Dark-brown, well decomposed. Fossil peat.
32	Portage	Atwater	----	400	3	Dark-brown, slightly fibrous. Tamarack, maple.
33	"	Brimfield	20	200	18	Dark-brown, partly fibrous and woody. Maple, ash, elm.
34	"	"	----	2	9	Brown, fibrous, cranberry-sphagnum meadow.
35	"	Franklin	----	30	10–15	Dark-brown, well decomposed. Tamarack muskeag.
36	"	Mantua	----	2,000	8	Dark-brown, well decomposed, partly silty. Maple, ash, elm.
37	"	Nelson	----	----	4	Nearly black and silty.
38	"	Ravenna	----	100 (?)	17	Brown, fibrous, partly well decomposed. Several associations.
39	Seneca	Big Spring	32	3,000 (?)	8	Dark-brown, almost structureless. Partly under cultivation.
40	Shelby	Van Buren	14	----	12	Same.
41	Stark	Canton	6– 7	100 (?)	19	Brown, fibrous, partly well decomposed. Under cultivation.
42	"	"	----	----	5	Same. Tamarack.

43	Stark	Canton	----	----	5	Same; partly under cultivation.
44	Summit	Copley	----	3,000	14	Dark-brown, moderately fibrous. Partly under cultivation.
45	"	Portage	----	----	17	Same. Tamarack.
46	"	Hudson	----	2,500	18	Dark-brown, well decomposed. Maple, ash, elm.
47	Trumbull	Greene	----	1,500	5	Dark-brown, fibrous, partly well decomposed. Tamarack.
48	Wayne	Baughman	----	300 (?)	11	Brown, fibrous, partly structureless. Under cultivation.
49	"	"	----	----	11	Reddish brown, fibrous. Under cultivation.
50	"	"	----	----	11	Nearly black, well decomposed. Under cultivation.
51	"	"	1-12	400	12	Brown, moderately fibrous. Tamarack.
52	"	"	----	----	5	Dark-brown, well decomposed. Partly under cultivation.
53	Williams	Florence	30	300	5	Brown, partly fibrous. Tamarack.
54	"	"	----	----	16	Same, but well decomposed.
55	"	Bridgewater	14-15	----	4	Same. Tamarack bog.
56	"	Superior	----	200	15	Dark-brown, moderately fibrous. Under cultivation.
57	"	Madison	----	40	9	Brown, fibrous, partly well decomposed. Tamarack.
58	Wyandot	Crawford	----	3,000	12	Dark-brown, well decomposed, somewhat woody. Under cultivation.
59	"	"	----	3,000	14	Same. Heath meadow.
60	"	"	----	3,000	14	Same. Under cultivation.
61	"	Crane	----	200	8	Dark-brown, well decomposed. Under cultivation.

TABLE 26—LOCATION, DESCRIPTION AND ANALYSES OF OHIO PEAT

	Laboratory Number	Moisture in air-dried sample	Volatile matter	Fixed carbon	Ash	Nitrogen	Sulphur	Iron	Thermal value in B. t. u.
1	73–11122	7.14	67.42	24.91	7.67	2.39	0.28	0.39	9070
2	44–10773	9.08	63.24	26.18	10.58	2.45	0.46	----	8966
3	60–11008	10.73	57.01	26.43	16.56	2.56	1.21	----	7567
4	24–	10.96	50.29	23.75	25.90	2.42	0.80	----	7520
5	64–11014	9.24	54.87	25.62	19.51	2.70	0.90	----	7448
6	89–12477	13.53	67.52	27.05	10.43	3.23	0.47	----	8683
7	49–10778	9.01	51.05	23.51	25.44	2.13	0.77	----	7504
8	88–12476	12.72	43.44	11.48	45.08	2.30	0.35	----	4637
9	87–12475	16.24	54.75	19.51	25.74	3.05	0.64	----	6797
10	82–11348	8.58	62.44	25.44	12.32	2.58	0.52	----	8420
11	83–11349	8.97	60.53	27.96	11.51	2.90	0.36	----	8566
12	66–11115	7.58	57.72	21.02	21.26	3.25	4.21	----	7603
13	49–10778	9.01	51.05	23.51	25.44	2.13	0.77	----	7504
14	51–10798	10.11	60.09	27.96	11.95	2.24	0.29	----	8741
15	85–12473	15.56	58.72	24.20	17.08	3.60	1.92	----	8248
16	38–10687	11.02	56.72	23.56	19.72	3.48	1.67	----	7749
17	61–11010	10.85	58.86	26.90	14.24	3.37	1.22	----	7916
18	62–11012	10.81	60.67	27.51	11.82	3.41	0.98	----	7996
19	72–11121	6.96	69.51	25.04	5.81	2.38	0.23	0.23	9571
20	42–10733	8.77	59.73	29.39	10.88	2.84	0.95	----	8914
21	64–11014	13.53	67.52	27.05	10.43	3.23	0.47	----	8683
22	43–10772	9.90	61.63	27.11	11.26	2.21	0.64	----	8122
23	40–10709	7.87	74.79	21.35	3.86	2.52	0.28	----	8338
24	41–10710	9.23	67.09	24.46	8.45	1.01	0.43	----	8626
25	50–10797	10.01	61.97	29.05	8.98	2.66	0.31	----	8737
26	70–11119	7.53	55.60	26.69	17.71	2.58	0.69	1.34	8168
27	71–11120	7.67	56.93	20.93	22.14	2.55	4.57	2.16	7132
28	81–11347	8.72	64.51	28.12	7.37	2.77	0.51	----	8915
29	80–11321	9.28	55.79	25.77	18.44	3.19	1.38	1.02	7781
30	79–11320	10.23	55.72	24.49	19.79	2.97	1.10	0.84	7762
31	84–12472	7.02	26.83	6.20	66.97	0.93	0.55	----	2914
32	55–10814	8.65	68.01	25.91	6.08	3.01	0.26	----	9443
33	52–10806	11.25	57.64	31.19	11.17	2.33	0.74	----	8564
34	53–10805	8.41	57.58	27.64	14.78	1.62	0.25	----	8996

35	56-10815	9.36	66.73	29.62	3.65	1.66	0.21	----	9736
36	47-10777	10.40	56.33	26.16	17.51	2.46	0.86	----	8190
37	46-11007	9.12	40.37	18.16	41.47	1.72	0.43	----	5121
38	54-10813	8.98	56.52	25.65	17.63	2.21	0.40	----	8402
39	38-10687	11.02	56.72	23.56	19.72	3.48	1.67	----	7749
40	86-12474	16.28	57.20	24.46	18.34	2.66	0.57	----	7675
41	74-11147	10.43	57.32	33.39	9.29	2.94	0.38	0.18	7794
42	75-11148	8.82	53.75	33.64	12.61	2.79	0.37	0.19	8498
43	76-11149	8.01	62.03	31.84	6.13	3.39	0.33	0.18	8842
44	59-10832	11.35	56.86	31.87	11.28	2.72	0.89	----	8861
45	58-10830	10.54	60.66	28.92	10.42	2.88	0.75	----	8703
46	57-10829	8.91	59.32	26.38	14.30	2.34	0.98	----	8372
47	45-10774	8.38	59.62	22.64	17.74	2.73	0.38	----	8147
48	67-11116	7.00	61.83	27.20	10.96	2.97	0.81	----	8608
49	68-11117	7.44	63.29	32.14	4.57	2.22	0.27	0.23	9569
50	69-11118	7.60	57.73	26.08	16.19	2.59	0.42	1.38	8280
51	77-11318	7.27	66.44	29.63	3.93	2.30	0.24	----	9148
52	78-11319	6.99	54.46	25.02	20.52	2.41	0.89	----	7875
53	33-13180	10.12	63.61	23.34	13.05	2.63	0.29	----	8345
54	34-13181	10.41	59.94	28.01	12.05	2.93	0.34	----	8532
55	63-11046	9.09	62.21	30.20	7.59	2.03	0.21	----	9389
56	90-13182	8.38	70.02	20.26	9.72	3.36	0.24	----	8914
57	65-11047	12.01	64.43	16.56	19.01	2.43	0.54	----	8905
58	35-10684	10.63	57.25	28.14	14.61	2.98	1.13	----	8378
59	36-10685	10.35	57.04	29.41	13.55	2.84	1.43	----	8482
60	37-10686	9.85	57.17	21.90	20.93	2.92	1.95	----	7682
61	39-10688	8.84	51.85	25.12	23.03	2.16	2.18	----	7666

The analyses, as might be expected, vary widely, but there is a certain uniformity in regard to their chemical character. With the exception of samples 46, 84 and 88, in which the ash content is very high and hence cannot be considered representative of peat specimens, the analyses show the following range in chemical composition (table 27):

TABLE 27

CHEMICAL ANALYSES OF OHIO PEAT—RANGE OF CHEMICAL COMPOSITION

	Minimum	Maximum
Moisture in air-dried samples	6.96	16.28
Volatile matter (moisture-free)	50.29	74.79
Fixed carbon	16.56	33.64
Ash	3.65	25.90
Nitrogen	1.01	3.60
Sulphur	0.21	4.57
Iron	0.18	2.16
Thermal value: British thermal units	7132.00	9736.00

For comparison the extreme percentages considered in connection with data from the analyses of Ohio coal, made from the State Geological Survey by Lord and Somermeier,[1] are shown in the following table 28.

TABLE 28

CHEMICAL ANALYSES OF OHIO COAL

	Minimum	Maximum
Moisture at 105° C.	2.46	10.93
Volatile matter	31.25	43.56
Fixed carbon	40.95	55.64
Ash	4.21	17.41
Nitrogen	0.86	1.44
Sulphur	0.51	6.14
Thermal value: British thermal units	10740.00	14020.00

The important advances in the use of gas, improvements in generators and gas producers, and investigation of the properties of gases derived from many kinds of fuel have demonstrated that gas can be profitably made from peat. This advance has gone on so rapidly that only mechanical engineers especially interested in power development

[1]Coal. Bull. Geol. Survey of Ohio, No. 9, 1908, pp. 290-301. See also p. 277.

realize the rate at which the change is taking place. Peat gas can be used for fuel and, after purification and enrichment, for lighting. Doubtless, also, it would without enrichment provide ample light if burned in incandescent types of burners.

The composition of peat gas is reported to vary considerably, being dependent upon the temperature of distillation, the character of the peat, the quantity of water in the peat, and the method of distilling.

Ryan[1] gives the following tables as indicating the average composition of peat gas:

	Per cent.
Methane (CH_4)	30
Carbon dioxide (CO_2)	30
Hydrogen (H_2)	19
Carbon monoxide (CO)	14
Heavy Hydrocarbons	7
Nitrogen (N_2)	Trace.

The gas after it has been purified by the removal of the carbon dioxide shows the following composition:

	Per cent.
Methane (CH_4)	42.5
Hydrogen (H_2)	27.5
Carbon monoxide (CO)	20.0
Heavy hydrocarbons	9.5
Carbon dioxide (CO_2)	.2
Nitrogen (N_2)	.3

According to official reports cited by Nystrom[2] the uncondensed gases before purification were found to have the following composition:

ANALYSIS OF UNCONDENSED GASES FROM RETORTS AT THE PEAT-COKING PLANT AT OLDENBUBG, GERMANY

Gas*	Weight	Volume
	Per cent.	*Per cent.*
Carbon dioxide (CO_2)	48.8	27.4
Oxygen (O)	2.8	2.2
Nitrogen (N)	25.5	22.5
Carbon monoxide (CO)	9.7	8.6
Methane (CH_4)	9.6	14.8
Other hydrocarbons (C_nH_m)	1.7	1.0
Hydrogen (H)	1.9	23.6

*This gas had a calorific value of 322 British thermal units per cubic foot.

[1]Ryan, Hugh, Reports upon the Irish peat industries, Pt. II: Econ. Proc. Roy. Soc. Dublin, Vol. I, pt. 13, pp. 520-521.

[2]Nystrom, E., Peat and lignite; their manufacture and uses in Europe. Can. Dept. Mines, Mines Branch, 1907, p. 180.

Davis[1] states that a report, from the Ziegler peat-coking plant at Beuerberg, gives the composition of the gases obtained there as follows:

ANALYSIS OF UNCONDENSED GASES FROM RETORTS AT THE PLANT AT BEUERBERG, GERMANY

Gas	Volume
	Per cent.
Carbon dioxide (CO_2)	15.5
Oxygen (O)	1.1
Carbon monoxide (CO)	20.4
Methane and other hydrocarbon gases (CH_4 and C_nH_m)	12.4
Hydrogen (H)	28.6
Nitrogen (N)	21.9

In view of these facts, the possibility of using peat for the manufacture of gas becomes an important topic for investigation in regions where peat is abundant.

Analyses of Bog Water.—The water from peat soils is relatively clear; in several places in the State it is used occasionally for drinking purposes. The suspended particles impart to it a tinge of color from olive-green to brown. The brown color of the bog water in deposits of northwestern and northeastern portions of the State may be due in part to dissolved matter and in part to the presence of free acids forming insoluble or difficultly soluble compounds in calcareous water. But there is no apparent relation between color and acidity. The highest percentages of acidity are found beneath tamarack trees. In areas occupied by deciduous trees acidity decreases and is notable only in the case of cool soil temperatures. On exposure to air acidity decreases slowly and the color of the solution darkens perceptibly. This is probably due to increased and more rapid oxidation and would indicate that color is produced largely by alkaline reactions.

The waters of the rivers and the ground water of Ohio lakes and ponds derive their mineral constituents from the underlying drift and native rocks. The several analyses[2] show that in calcium and magnesium content they are fairly uniform and contain sufficient mineral salts for plant growth. The carbonates of calcium and magnesium are the leading bases, but potassium and sodium occur sometimes in small quantities. Iron is unfailingly present. Water from greater depths and from flowing wells holds sulphates, and nearly all the water of the Ohio shale system, and especially that in the limestone region, is characterized by the presence of sulphides, particularly hydrogen sulphide.

[1]Davis, Ch. A., The uses of peat. U. S. Bureau of Mines, Bull. 16, 1911, p. 135.
[2]Rivers and deep-ground waters of Ohio. Report of Ohio State Board of Health, 1897–1898, pp. 47-120, and 179-259; also 1906, pp. 425-437.

Through the considerate interest of Professor C. W. Foulk, analyses of samples of bog water and lake water have been made. The data are given in tables 29 and 30. The samples were obtained in the latter part of May, 1910, and early in April, 1912, respectively. In table 30 the nitrogen content was determined by the Kjeldahl method of analyses.

TABLE 29

CHEMICAL ANALYSES OF BOG WATER AND LAKE WATER FROM CRANBERRY ISLAND, BUCKEYE LAKE

Constituents in parts per million	Bog water from cranberry-sphagnum association	Bog water from alder-shrub association	Lake water
Nitrogen as albuminoid ammonia	10.34	11.48	4.50
Nitogen as free ammonia	15.19	8.24	2.95
Nitrogen as nitrites	0.0005	0.0003	0.00000
Nitrogen as nitrates	0.20	0.20	0.1000
Chlorine	0.30	1.00	1.00
Required oxygen	71.80	70.30	3.70
Alkalinity (as $CaCO_3$)	30.00	40.00	75.00
Incrustants (as $CaCO_3$)	74.00	72.00	76.00
Total solids	140.00	160.00	200.00
Loss on ignition	100.00	20.00	4.00

TABLE 30

CHEMICAL ANALYSES OF BOG WATER AND LAKE WATER FROM CRANBERRY ISLAND, BUCKEYE LAKE

Constituents in parts per million	Bog water from cranberry-sphagnum association	Bog water from alder-shrub association	Lake water
Nitrogen as organic ammonia	3.35	4.75	0.172
Nitrogen as free ammonia	0.06	0.32	0.08
Nitrogen as nitrites	0.004	0.004	0.012
Nitrogen as nitrates	0.168	0.115	0.385
Chlorine	1.00	1.50	3.00
Required oxygen	62.00	89.50	3.00
Alkalinity (as $CaCO_3$)	16.40	11.30	70.10
Incrustants (as $CaCO_3$)	120.00	138.00	62.00
Total solids	309.00	423.00	196.00
Loss on ignition	201.00	221.00	49.00

The marked difference between the total mineral content of bog water and that of the adjoining lake is notable. This indicates clearly that the ground water is similar in character and of special importance in the early stages of the formation of peat deposits, but that with further accumulation of plant débris its relation to the vegetation is of less moment. The analysis shows how little of the salts is derived from the mineral subsoil. The diffusion property of peat and its retention of salts by absorption, as is well known, is greater than that of other soils, and is still further increased by the presence of calcium salts.

Tables 29 and 30 also show conclusively that only a small amount of nitrogenous substances can be extracted from peat by means of water, and that the solubility of a coarsely fibrous peat is less than that at a more advanced stage of decomposition. The relatively low amount of free ammonia and the larger quantity of oxygen consumed indicate that the organic matter is in early transition stages of decomposition. This condition clearly points to the fact that the disintegration products arise mainly through the action of microörganisms. It is interesting to note the small quantity of nitrites and nitrates, which ranges from a few thousandths to a few hundreths parts per million and yet is ample to support plant growth. Practically all of the nitrogenous matter is, therefore, of organic nature.

The osmotic pressure of these solutions is the same as that of Ohio lakes and of peat deposits of other states,[1] the average lowering of the freezing point varying between 0.005° and 0.010° when compared with that of distilled water. The acidity of the solutions varies from less than 0.00075 to 0.004 normal acid when titrated with an 0.05 normal NaOH solution and phenolphthalein. Peat soil is alkaline at depths near the marly subsoil. The reactions of free humus acids noted in peat can be attributed to the colloidal adsorption of plant tissue, retaining, as Baumann and Gully[2] have lately shown, a greater proportion of the basic ions of any dissolved salt than of the acid. The basic mineral constituents of peat ash are almost the same as those retained by the adsorbent power of the colloids of sphagnum cells.

The suggestion has been made that acidity may be correlated with low soil temperature. Experiments conducted by various writers and experiment stations, notably that of Rhode Island, seem to show that certain species such as cranberry, blueberry, blackberry, bean and others, favor acid soil conditions while for other plants acidity is not advantageous for growth and hence becomes a factor in the selection of species. Apparently a combination of biochemical and physical conditions brings acidity into existence in the soil as a temporary transition stage. Very little is known about the matter (p. 386).

The Reducing Action of Peat Soils.—It is a well known fact that fresh samples of peat upon exposure to the air absorb oxygen with great rapidity. Soil-sampling tests show that this power is strong in the cranberry-sphagnum peat, reaching a maximum in areas where the peat substratum is compact and less coarsely fibrous, and decreasing toward the border zone along the margin of the lake. Judged by the quickness with which the material darkens and the intensity of the color, the reducing action increases, for example, on Cranberry Island from any

[1]Livingston, B. E., The Physiological properties of Bog Water. Bot. Gazette, Vol. XXXIX, 1905, pp. 348-355.

[2]Bauman, A., und Gully, E., Ueber die freien Humussäuren des Hochmoores. Mitt. k. Bayr, Moorkulturanst, 1910, pp. 31-156.

marginal point to the central zone, and decreases as the opposite shore is approached. Reducing action becomes greater with the depth of the deposit.

The reducing power of peat is shown clearly by the addition of a starch-iodide solution. The observable action is variable, as already mentioned; the blue color disappears rapidly in soils from the cranberry-sphagnum area; the solution is greatly lightened with soils nearer the margin of the lake; no action is detected with those along the margin. Various dyes, such as litmus, methylene blue and others, decolorize similarly. The absence of sulphur in the analysis of several samples of peat is possibly due to its complete conversion to hydrogen sulphide. This gas is a product of reduction and has been detected by means of lead acetate paper.

Especially interesting in this connection is the presence of pyrite in peat beds. A number of deposits were examined in which ferric sulphide as pyrite was found to occur disseminated, and frequently in small isolated areas, within the peat bed. Several samples contained a fairly large amount of pyrite; chemical analysis revealed the presence of sulphur (pp. 58, 98, 142, 366), in one example to the amount of 4.57 per cent. Sulphates are especially characteristic in the water of the great Ohio shales, and iron is unfailingly present, often in notable quantity. Under the mass of more actively disintegrating vegetation the sulphates are robbed of the oxygen and, thus undergoing reducing action, form pyrite.

Tests such as these fail to show whether the reducing power in peat soils is produced by microörganisms, is due to enzymes, or is caused by external chemical or bacterial metabolic products. Nothing absolutely certain is known regarding the composition and the nature of these reducing substances in peat. To some extent they seem to be of bacterial origin (p. 349), but they have not at present been fully studied. Apart from their destruction by aeration, tillage and heat, and their adsorption by insoluble substances such as quartz, kaolin, carborundum, lampblack, and others (tables 10 to 16), uncertainty exists as to whether the reducing substances in bogs are colloidal compounds comparable in properties to unsaturated fatty acids, to substances which possess the characteristics of certain organic reducing ferments, or to residual by-products of an incomplete disintegration of peat. They unquestionably reduce oxygen-containing compounds in contact with them; their action is most marked where microörganisms play a part in decomposing organic matter; and the amount, it seems, reaches a maximum in early autumn. It should be stated further that toxicity and the reducing action of peat soil and that of the decomposing organic matter, which retard oxidation in the soil, are not necessarily the same phenomena. An increase in the amount of oxygen does not always decrease toxicity or the reducing power of the soil, and hence the amount of oxygen absorbed cannot be taken as the measure of the total action of these conditions.

Reduction processes are predominant in the early stages of peat formation, but are less manifest as the concomitant plant associations are succeeded by others, and especially when deciduous forests prevail. The same factors which decrease the toxicity of the habitat and the accompanying reducing processes, favor an increase in the rate of oxidation and thus influence the character and nature of the succession. The greater oxidation, therefore, in the known productive peat soils, would seem to be due to the activity of a different set of microörganisms, which by enzymic action or otherwise hasten the formation of compounds of an assimilable nature (table 22). The excessive oxygen avidity of peat soils in the early formation stages must undoubtedly be injurious to plants, unless the plants, indigenous or invaders, are likewise able to exhibit oxidizing or reducing powers. The reducing processes in a soil very likely activate oxidative powers in plants. The various reactions of fungi, micorhiza, alder tubercles, bacteria, and the roots of higher plants growing in peat and humus soils should on that account be made the subject of considerably greater and more detailed study (p. 353). The consideration of the relation between plant societies, relative physiological aridity, and microörganisms, with their reduction and oxidation processes in the soil, has scarcely passed beyond the theoretic field of speculation, and yet it is this very relation which makes the problem especially interesting. There is need here of experimental work of considerable scope.

The Ash of Peat, Its General Effects and Relation to Fuel Value.—For technical purposes the ash content in peat analyses is one of the most important factors to be considered. In the majority of cases low thermal value is traceable in a nearly direct proportion to high ash content. It is only in regions where a peat deposit can be used for local purposes and the material does not need to be brought from great distances, that quantity is of more importance than quality and precautions regarding ash and degree of decomposition may be waived. The heating value does not always diminish as the ash content increases, since often the lack of correlation is due to the escape of volatile matter in deteriorating, weathered or poorly decomposed peat. Various tests made in several countries show that, other things being equal, the de-

COMPARATIVE CALORIFIC VALUE OF PEAT WITH VARIOUS AMOUNTS OF ASH AND WATER

Ash.	Water.	Calorific value per pound.	Ash.	Water.	Calorific value per pound.
Per cent.	*Per cent.*	*B. t. u.*	*Per cent.*	*Per cent.*	*B. t. u.*
Free.	Free.	10726	10	Free.	9653
4	Free.	10297	20	Free.	8581
4	11	9117	10	15	8045
4	15	8688	10	20	7508
4	25	7615	20	15	6973
4	30	7079	20	20	6436
4	50	4934			

crease in thermal value is approximately at the rate of 80 to 90 British thermal units for every one per cent. increase in ash content. The moisture content of peat also causes a difference in the thermal value, as shown by the above table, p. 374, cited from Davis.[1]

On the other hand, remarkably high thermal values are often due to the unusually well decomposed condition of the material combined, of course, with a relatively low percentage of ash. In general, in the low grade peat the ash content ranges between 15 to 25 per cent. while in the high grade it varies from 3 to 5 per cent.

In Ohio peat there is a fairly close and definite relation between the heating value and the variations in ash content. Thus, if the analyses are arranged in order of their thermal value, or in order of each of the elements of the analyses reported, a table of comparative values of peat samples would show clearly a relationship between thermal value and other factors. In a general way only is there a relationship demonstrable; for other components, such as chemical composition of ash, the type of plants from which the peat has been derived, exposure

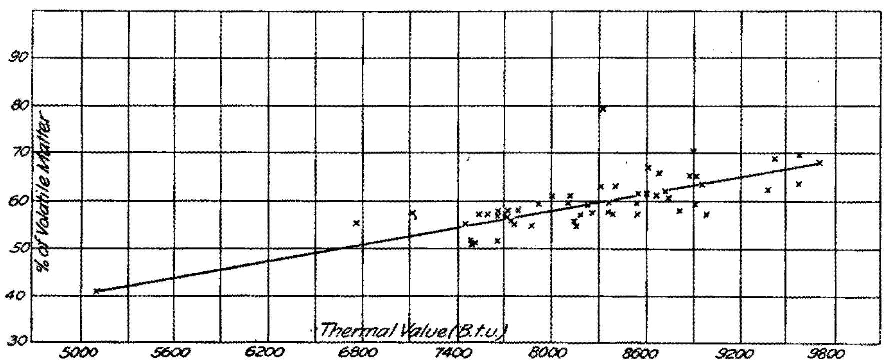


Fig. 27.—Diagram showing relation between thermal value and volatile matter in Ohio Peat.

to air or heat, and the degree of disintegration, are undoubtedly the factors necessary in the explanation of irregularities. From the study of the origin and formation of peat deposits it is evident that peat, lacking as it does in homogeneity of structure and composition, will invariably give analyses of thermal units varying within unrelated limits. Because of this fact it will usually be of advantage to sample and test all deposits individually, before commercial exploitation is attempted.

In figures 27, 28 and 29 the relations between fuel value of Ohio peat and the more important factors influencing it are shown graphically. Upon the horizontal line or ordinate of each diagram the position of every analyzed sample in table 26 is given with reference to a series of increasing thermal values. The vertical line or abscissa shows the respective modifying factors arranged in an order of increasing magni-

[1]Davis, Charles A., The uses of peat. U. S. Bureau of Mines, Bull 16, 1911, p. 59.

tude. A line is drawn connecting in each case the poorest with the best sample of peat. The figures show at a glance the relations which hold true for absolutely dry peat. Moisture also causes a difference in thermal value, lowering it nearly in proportion to the amount of water present, but effect and limits of variation are probably the same as appear on the diagrams.

The diagram in Fig. 27 shows that an increase in the percentage of volatile matter means a higher thermal value. In only one instance is this relationship at variance. The sample (No. 40) has the maximum of 74.79 per cent. volatile matter and the calorimetric determination gives only 8,338 British thermal units. The percentage of fixed carbon and the ash content are low also, being 21.35 per cent. and 3.86 per cent. respectively. The cause of this lack of correspondence may be looked for in a possible deterioration of the material but is due probably to the quality and character of the peat. The calorific value of a sample is proportional to the amount of hydrocarbons and carbon present in the

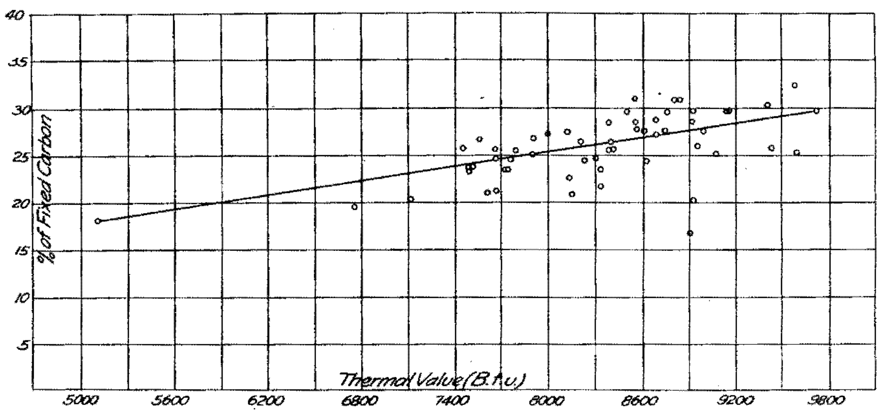


Fig 28.—Diagram showing relation between thermal value and fixed carbon in Ohio peat.

organic material. Fixed carbon does not represent all the carbon but merely the combustible matter that is left when peat is coked. It is not a definite ingredient, but the result obtained from a special mode of treating peat.

The diagram in Fig. 28 brings out the fact that an increase in fixed carbon is usually accompanied by an increase in thermal value. This simply means that plant debris composed of cellulose and soft tissues contains more hydrocarbons than woody matter, and that well carbonized peat has a higher fuel value than the poorly decomposed or weathered product. An imperfect parallelism is, therefore, traceable between the distribution of circles in the diagram of Fig. 28 and that of the crosses in the diagram of Fig. 27. Two exceptions are noticeable. The sample (Nos. 65 and 90) along the line of ordinates, having the value of 15 and 20 per cent. respectively, show a remarkably high fuel value as compared with the quantity of fixed carbon present. These two cases may also be due to the better quality of the peat in texture and composition, for the percentage of ash is relatively high, varying between 10 and 20 per cent.

In a similar manner Figure 29 shows that the quantity of ash determines within certain limits the fuel value of peat. The relation is here inverse and reciprocal; that is, the increase in thermal value is nearly in direct proportion to the decrease in the amount of mineral matter present. It should be added here that ash does not stand for the amount of mineral matter as it exists in the peat. Considerable loss in weight of ash is involved in oxidation and in other sources ac-

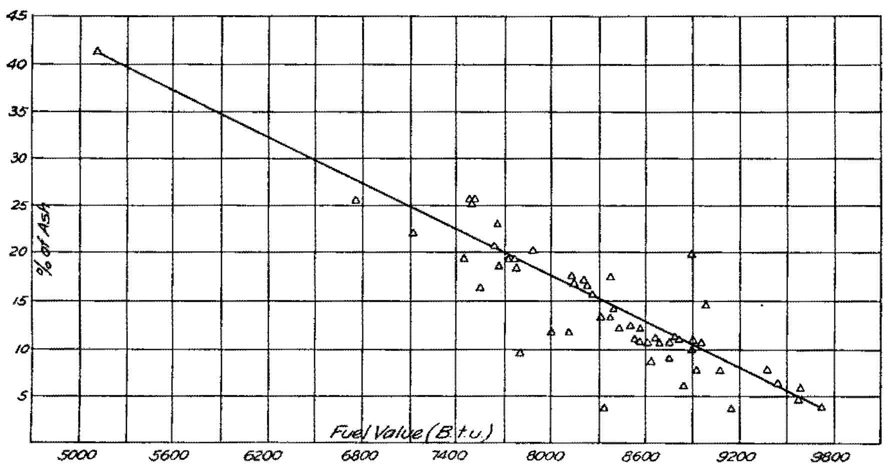


Fig. 29.—Diagram showing fuel value in relation to percentage of ash in Ohio peat.

companying combustion. The figure indicates, at a glance, the well known fact that to raise and maintain the temperature of ash to that of the surrounding combustible matter requires a large amount of heat which is necessarily wasted in the operation.

A few exceptions—in this case the three examples mentioned above—show a greater number of British thermal units than is apparent from considerations of the theoretical heating value. These variations obtained in the calorimetric determination are undoubtedly due to differences in degree of decomposition as well as the quality of the peat. In general, disintegrating plant tissue of a coarse, fibrous or woody texture is less valuable for fuel purposes than the finer-grained and dark-colored type. The relatively large amount of oxygen in hydrocarbons, present in the better grade material itself, supports combustion even under conditions of poor air supply. Peat usually requires less draft than other fuels.

Chemical Composition of Peat Ash.—The ash was not analyzed by the Pittsburgh laboratory of the Bureau of Mines, but partial analyses were made by Prof. J. W. Ames of the Ohio Agricultural Experiment

Station. They have been very generously placed at the writer's disposal, in advance of publication elsewhere, and are given here in table 31. The samples with the laboratory number 5302 to 5306 are from the peat land owned by the Peterson & Wright Company, of Akron, Ohio; the samples with the laboratory number 14460 to 14465 are from the tract of the Horr-Warner Company at Lodi; number 14162 is from an area near McGuffey. A description of the deposits and the character and depth of the peat has been given in Chapter III. The notes which accompany the samples read as follows:

Lab. No.	Character of peat and crop
5302.	Sample of poor peat. Produces fine red beets. Carrots grow well, but have pale watery centers, and are tasteless. Beets keep finely, but carrots will not keep at all. Farmed four years.
5303.	Poor quality of peat. Full of fine, shiny particles, supposed to be injurious. Farmed four years.
5304.	Poor peat soil. Plat 1 of test; never received lime or fertilizer.
5305.	Peat first year broken; absolutely new; plowed 6-inches deep; celery good.
5306.	Good peat soil. Has received lime and a mixture of wood and coal ashes. Farmed four years; three years successively in onions; west of ditch.
14162.	Sample of peat soil from an onion field, collected by W. J. Mathews, McGuffey, Ohio, June 3, 1907.
14460.	Peat soil from onion fields at Garden Isle of the Horr-Warner Co., Wellington, Ohio. Poor crop of onions. Ditch filled in for 2 years; 6-acre field.
14461.	From good peat land in 6-acre field; under cultivation 16 years.
14462.	Peat soil from poor crop in roadway field.
14463.	Peat soil from roadway; fine onions.
14464.	In east field; poor onions.
14465.	Same field as 14464; good onions.

TABLE 31

ANALYSES OF PEAT SOILS, CHEMICAL DEPARTMENT, OHIO AGRICULTURAL EXPERIMENT STATION—TOTAL AMOUNTS FOUND

Lab. no.	Locality	Ash	Mn	SiO_2	SO_3	Al_2O_3 and Fe_2O_3	CaO	MgO	Na_2O	P_2O_5	K_2O	N
5302	Akron	9.66	.0056	3.21	1.20	2.04	2.390	.311	----	.299	.1594	3.42
5303	"	14.58	.0099	6.18	.97	2.91	2.870	.331	----	.345	.3117	3.24
5304	"	9.84	.0220	4.05	1.03	2.19	3.580	.361	----	.342	.1531	3.38
5305	"	14.38	.0332	5.26	1.03	2.44	3.650	.297	----	.469	.2956	3.10
5306	"	11.65	.0515	4.01	.88	2.65	2.800	.345	----	.337	.1860	3.18
14460	Lodi	----	----	----	----	5.15	4.529	.570	2.366	.506	.4753	----
14461	"	----	----	----	----	4.24	2.570	.420	3.373	.342	.3239	----
14462	"	----	----	----	----	5.62	4.060	.650	2.040	.374	.3569	----
14463	"	----	----	----	----	11.15	2.210	.660	1.944	.256	.9835	----
14464	"	----	----	----	----	4.08	3.050	.630	1.066	.373	.3376	----
14465	"	----	----	----	----	4.18	2.340	.420	2.018	.429	.3445	----
14162	McGuffey	----	----	----	----	----	3.585	----	----	.370	.4720	2.48

These analyses of the ash constituents of peat indicate that the mineral salts are largely of external origin. They are the sediments brought in by stream or carried down by erosion and wind. The material is found mostly as silica in the form of sand and silt, as alumina and silica in the form of clay, and as calcium carbonate in the form of marl. The distribution of ash in peat beds is of considerable practical moment. The samples, which have not been selected by the writer, often include portions of the lower silty layers. Hence a much lower figure than indicated could be obtained in the analyses. In only a few cases is the silty material distributed throughout the whole bed, and practically uniform in various parts of the deposit.

The ash of many plants contains silica, showing that some compound of silicon is removed and assimilated by the plants. It does not serve, however, as a food material, but as a mechanical constituent to give firmness to the slender stalks of grasses and sedges. It is said that humic acids decompose silicates and hold them in solution, forming a series of silico-azo-humic acids by a reaction between organic nitrogen compounds and the silica. The various relationships which enter into the problem have not been clearly traced. Only a general tendency has been demonstrated. The proportion of silica has been found to be high at times when the disintegrating organic matter is high also. Silica as well as iron is often precipitated by the oxidation of humus acids.

Calcium is an essential constituent in the ash of peat deposits overlying the western portion of Ohio. It is found in almost all streams and natural water basins. Limestone is the carbonate and gypsum the sulphate of calcium. Living organisms, but especially several aquatic plants such as *Chara* and a few blue-green algae, and among animals the crustaceans and mollusks, withdraw calcium carbonate from solutions in water. With the death of the organisms the material becomes permanently deposited in the form of marl upon the floor of peat depositing lakes and ponds. Marl does not redissolve readily, but calcium phosphate is dissolved perceptibly in water rich in organic matter.

The interpretation of sulphur in peat bogs is not easy for several reasons. Bacterial organisms and low algae in the presence of organic matter reduce sulphates with elimination of hydrogen sulphide and the formation of carbonates. Hydrogen sulphide fermentation is especially conspicuous in small water pockets and in the bottom water of bogs. While in one bog the evidence of sulphur reduction may be clear, as at Buckeye Lake for example, in other peat deposits, as in those of Medina, Huron and Hardin counties, a process of oxidation of pyrite and conversion to sulphates may be operative without a reduction of these sulphides. In still another deposit the considerable quantity of sulphur may be found associated with the fact that the deposit is resting on gypsum strata or is fed with water containing hydrogen sulphide in solution.

Iron, manganese and other metals are not infrequently found in the ash of peat. Of these the iron compounds, such as carbonate, sulphate, sulphide or oxide, are the more abundant. Ferrous carbonate, when oxidized by the atmosphere, forms the film of ferric hydroxide which is noticeable on the standing water of several local bogs. In many cases iron bacteria absorb ferrous carbonate in solution and redeposit the iron as ferric hydroxide. Ferrous sulphate is chiefly derived from springs, and acid solutions of it are formed by the oxidation of pyrite. Iron may be precipitated from solution by calcium carbonate, but more commonly by contact with organic matter. It may be separated out by any of the several reactions indicated, but whether its precipitation takes place by oxidation, by organic matter or by calcium carbonate, the various compounds of it are the material from which bog-iron is formed. Bog-iron usually occurs along the margin, more rarely under or in the center of bogs and marshes.

Peat as a Fertilizer.—The question of soil fertility and its causes is a very old one and has occupied the attention of every one connected with agriculture. The problem, it seems, has no simple solution. The practices of agriculture, when interpreted in the light of modern science, show that the oldest, the most densely populated and most intensively cultivated lands are more productive today, unit for unit, than the newer soils, such as those of the United States. No single factor can be cited as the cause determining or limiting yield of crops[1] or the growth of plants (p. 307). The soil is not a mixture of particles only; it contains gases, solutions, enzymes, disintegrating organic matter, and especially, living organisms, such as bacteria, fungi and various forms of animal life, which continually modify the physical and chemical changes going on in the soil. These forms of life also affect the sanitary condition of the soil as well as the plants growing upon it, and thus influence productivity. The soil is a living world in itself; hence all that science can do is to determine the efficient natural process for maintenance of soil productivity,[2] and to disentangle the various factors which favor or limit the growth of crops.

Recently, students of ecology and of soils have taken the position that the chief relation between plants and their habitat and, therefore, crop production, probably lies in the supply of water to the plants, for the most part climatic conditions such as precipitation and temperature prevailing at the time of the period of maximum growth of plants. Since soils differ from one another far more in the amount of water required by growing plants than in the amount of essential mineral salts, the yield of crops is more often limited by the available water content than any other single factor. Agricultural agitation, however, has been for many years very strongly toward chemical analysis as the

[1]Hall, A. D., The Fertility of the Soil. Science, Vol. XXXII, 1910, pp. 363-371.
[2]Chamberlin, T. C., Soil productivity. Science, Vol. XXXIII, 1911, pp. 225-227.

decisive mode of attack and guidance in questions of soil fertility. It is thought that the soil's power of producing crops under cultivation is determined by its content of those materials which are taken from it by the plants, and that to restore the productivity of the soil, it is necessary only to restore the ingredients essential to plants. The commercial fertilizers applied are usually valued on the basis of their content in available or soluble nitrogen, potash and phosphoric acid compounds. Alarming forecasts have appeared from time to time[1] as to the available supply of "plant food in the soil," notwithstanding the fact that these constituents are not the food of plants, that the action of fertilizers is on the soil[2] as well as on the plant, and that any normal soil will contain quantities of these materials for a long time to come. It is well known that the food which plants use is the energy locked up in the organic compounds of seeds and fruits. The so-called indispensable elements of the ash—potassium, iron, calcium, magnesium and others—serve, in part, as raw materials for protein synthesis, but their main mode of action, in all probability, consists in combining with and removing the inevitable decomposition products of protoplasm and of some of the unstable proteins and carbohydrates associated with nutritive processes. The presence or absence of particular compounds in the cells interferes with the usual functions and exerts a profound influence upon the general course of development of the plant, dwarfing and otherwise injuring tissues. The amount of mineral salts or ash in bog plants constitutes less than one per cent.—in most land plants not more than two per cent. of the total weight of the water-free organic substance—and in regions where the soil water contains little mineral matter in solution, plants grow equally as well and contain a proportionately smaller percentage of ash than those of the same species where the water has more soluble mineral salts. Yet literature and text books in agriculture contain numerous references to the rôle of mineral salts as the "food" of plants, rather than as raw materials for protein synthesis and functional correlation. For example, year after year generations of bog plants have succeeded one another in one water basin since the last ice-age at an ever increasing distance from the mineral subsoil. If the growth of plants depends upon the amount of mineral salts they can get from the soil, why is it that growth and reproduction of bog plants are not decreased or limited?

To show the quantities of the fertilizer elements in peat which are absolutely essential for protoplasmic activity, for growth, and for the ripening of fruit and seeds in this continuous succession of plants, a number of peat samples were submitted to the late Prof. N. W. Lord

[1]Hopkins, C. G., Soil fertility and permanent agriculture, 1911; also Plant food in relation to soil fertility. Ills. Ag. Exp. Sta., Circular 155, 1912.

[2]Cameron, F. K., The soil solution. 1911.

Schreiner, O., and Skinner, J. J., The toxic action of organic compounds as modified by fertilizer salts. Bot. Gaz., Vol. LIV, 1912, pp. 31-48.

for an analysis with a view of determining the fertilizer value of peat soils. The determinations of the ash constituents (table 32) were made in the same way as in fertilizer analyses. They may be regarded as exact within about 0.05 per cent. This is equivalent to reporting the potash and phosphoric acid as present in traces only and leaves the actual quantitative figure without much significance.

A few analyses of Ohio peat (numbers 14 to 21) are given by Bonser[1] which may be cited profitably in this connection. Attention is called also to the data on phosphoric acid and potash in table 31. The results are as follows:

TABLE 32

FERTILIZER VALUE OF OHIO PEAT

Locality	Sample no.	Nitrogen equivalent to ammonia	Phosphoric acid			Potash
			Total	Insoluble	Available	
1. Lodi	70	2.20	0.19	0.13	0.06	0.640
2. Lodi, diseased	71	2.38	0.37	0.15	0.22	0.640
3. Edgerton	82	2.75	0.13	0.13	---	0.314
4. "	83	1.51	0.29	0.15	0.14	0.150
5. Orrville	68	2.52	0.06	0.06	---	0.278
6. "	67	2.58	0.34	0.07	0.27	0.310
7. "	69	2.90	0.43	0.06	0.37	0.198
8. Cranberry Prairie	81	2.70	0.15	0.06	0.09	0.202
9. Buckeye Lake	41	0.80	0.03	---	0.03	0.120
10. " "	40	2.55	0.03	---	0.03	0.120
11. Fox Lake	77	2.41	0.28	---	---	0.150
12. Bradley Pond	51	2.24	0.19	---	---	0.270
13. Mantua Bog	47	2.46	0.42	---	---	0.190
14. Hog Creek Marsh	--	1.26	0.10	---	---	0.100
15. " " "	--	1.49	0.38	---	---	Trace
16. Scioto Marsh	61 (?)	1.09	0.09	---	---	0.100
17. " "	--	0.95	0.13	---	---	Trace
18. " "	--	0.90	0.09	---	---	0.100
19. " "	--	1.40	0.07	---	---	Trace
20. " "	--	1.44	0.10	---	---	0.150
21. Big Spring Prairie	37 (?)	0.99	Trace	---	---	Trace
22. Mixed farm manure	--	0.50	0.26	---	---	0.630

These analyses show very clearly that the quantity of potash and phosphoric acid in peat is very small and that the value of peat and humus as a fertilizer for "exhausted" land does not depend so much on the chemical composition as on the physical effect upon land soils. There is no objection to the use of the material as a filler in fertilizers, for besides being cheap and abundant, it provides the organic matter

[1]Bonser, T. A., Ecological study of Big Spring Prairie. Ohio State Acad. of Sci., Vol. III, 1903, pp. 1-96.

in which all chemical fertilizers are most deficient and serves as a more valuable diluent than inert sand or plaster. No attempt, it is needless to add, should be made to charge for peat the same price that is paid for complete fertilizers.

In order to utilize large deposits profitably and with benefit to agricultural interests, peat should not be dried in a kiln and granulated before being placed on the market. Chemical as well as bacteriological and physiological experiments distinguish with accuracy the varying degrees of quality and usefulness of the material. The methods have shown that the organic compounds, especially the nitrogenous ones, of air-dried peat are more available to plants than those of the material treated in kilns at a high temperature. Moreover, air-dried organic matter has the greater water-holding power, and does not resist the decomposition processes in the soil. The process of granulation should not be used, since the readily decomposable constituents vanish too rapidly, and granular peat does not improve the aeration of the soil. When applied to the land in a partially disintegrated condition, and especially in composts well mixed with barnyard or stable manure, peat increases the water-content of the soil and its heat conductivity; it influences the solubility of the soil minerals and affects the aeration and the character of the soil organisms. Bacteria and fungi are indispensable for the production of available nitrogenous and other compounds containing phosphates and potash, and for converting the higher compounds of the organic matter into simpler ones. Fibrous and brown peat freshly dug should not be used in the wet condition. It will yield better returns if properly composted with coarse manure—thin layers of peat alternating with those of the stable refuse to the height of several feet. The whole stack should be allowed to stand for several months and during that time should be turned over occasionally. Peat, if air-dried, may be used to still better advantage after having served as bedding for stock or as an absorbent of moist, waste organic matter and the nitrogenous liquids of stables and barnyards which ordinarily are not retained.

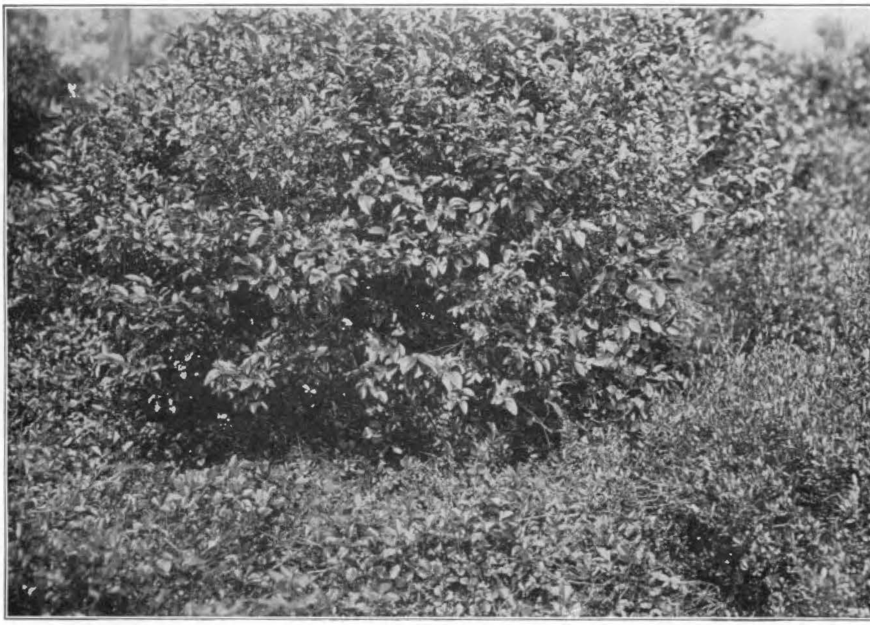
Peat and humus cannot be a significant source of mineral salts and mineral fertilizers. Many farmers think it advisable to burn over the surface of a peat deposit in order to obtain peat ashes for agricultural purposes. The weight of evidence gathered shows that this is a mistaken waste, if for no other reason than the greater value of the peat itself. Ashes from wood, peat or any other vegetable tissue contains a disproportionately small percentage of mineral salts. Where the ash content of peat is extremely variable in quantity and exceeds three per cent. of the dry weight of the peat, the excess may safely be attributed to both wind and water action. The larger proportion is then silty sediment, the sand and clay derived from flooding by streams, or the rain wash from hillsides and cultivated areas. It forms practically the same abundant constituent of all mineral soils, and is of little value as raw material for plant growth. On the other hand, peat of a low ash content, because of the greater amount and purity of plant tissue, would have a relatively greater quantity of potash and phosphoric acid salts. The value of peat as a direct fertilizer depends on the nutritive value of the different organic carbon and nitrogen compounds and the character of the processes in the plants by which these compounds are absorbed (pp. 335-342). But the variable composition of peat and humus renders it difficult to determine, except by means of carefully devised and controlled experiments, what organic substances are actually absorbed by plants and are valuable or injurious to nutritive metabolism.

Peat in Agriculture.—Very little work has as yet been attempted in the United States on the utilization of peat soils in agriculture. In Europe, soils of this nature have been reclaimed for many years by drainage and cultivation. The problems involved in the proper value of peat soils, in increasing the rate of yield, and the diversity of crops have been the subject of careful and extensive study by trained specialists. European governments have not only aided in this important work of establishing and maintaining experiment stations at peat deposits, but have carried on practical experiments on a large and systematic scale to develop the areas of peat and marsh land.

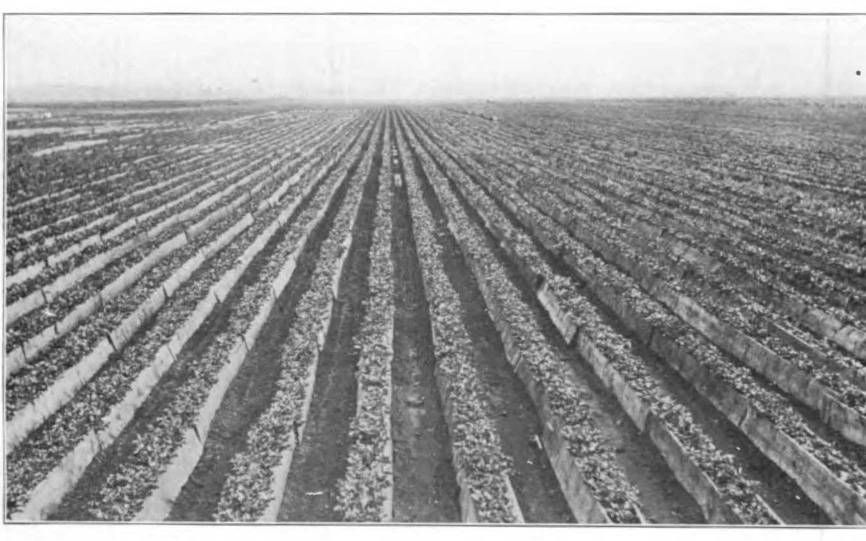
Many farmers are of the opinion that heath plants, such as cranberry (Plate VII, A), and high-bush blueberry (Plate VIII, A), could be grown successfully upon peat deposits, and should be cultivated on a commercial scale. It is a matter of great regret that nothing has been done so far to grow these plants in bogs that are best adapted to them. In the eastern states, the cultivation of cranberries, and to some extent that of the high-bush blueberry, has proved remunerative. An interesting bulletin[1] shows that blueberries afford good promise of success in the field, and that ultimately improved varieties of these plants will be obtained. There are no reasons why the same success should not be obtained in Ohio.

In preparing a peat deposit for the cultivation of agricultural crops, or a partly filled bog for the cultivation of the economic heath plants —the cranberry and the high-bush blueberry—the water level, if at or near the surface, should be lowered at least one foot by effective ditching and draining. After this has been accomplished the vegetation cover should be removed by the process known as "turfing," which carries away all the native plant growth, the partly decayed stumps and other woody débris. The naked peat soil is then tilled and furrowed. There are peat deposits in Ohio under cultivation which, according to the testimony of their owners, have not failed for at least ten consecutive years to produce a crop of corn without any applica-

[1]Coville, F. V., Experiments in Blueberry culture. U. S. Dept. of Agriculture, Bureau of Plant Industry, Bull. 193, 1910.



A.—The high-bush blueberry (*Vaccinium corymbosum*) in fruit.
(*Photograph by L. King.*)



B.—A view of the celery crop on a peat deposit under cultivation. Garden Isle, Lodi.

tion of manure or fertilizer. On the other hand, observations in various parts of the country, where peat soils are common, indicate that, generally, only one or two crops have been taken from newly cleared peat land. Various localities with diseased and unproductive soils have been pointed out in a preceding chapter, and some of the causes of the infertility have been suggested. In such cases fodder grasses like timothy, red top, blue grass, and later clover yield good crops for a number of years until the surface layers of the soil are blackened and disintegrated. If garden truck is desired, a good supply of well decomposed barnyard manure should be mixed thoroughly with the soil, plowed down and later worked over with harrow and boat. Barnyard manure is particularly effective in adding to the value and productiveness of peat soils, since it promotes the decomposition of the peat by introducing fungi and bacteria, which aid decay and hasten humus formation. Methods of composting, and the uses of even poorly decomposed peat as an absorbent in stables, for saving valuable nitrogenous waste matter, or as litter and bedding for stock have been mentioned in another place. It should be added that protecting hedges are often needed to break the force of winds and to prevent the removal of the surface soil and seeds. The treatment of peat land is expensive when well done, costing perhaps $300.00 to $400.00 an acre, but its value is often $1,000.00 an acre with a gross revenue of, at least, $300.00 an acre.

The plants selected should be as a rule, such as can well endure drought and early frosts. Celery (Plate VIII, B), onion, lettuce, carrot, parsnip, beet, radish, potato, strawberry, lupine, buckwheat, spinach, cabbage, turnip, peppermint are among the most valuable crops which are grown upon intensively farmed areas. The bacterial condition of the freshly drained organic soils is often not favorable to growth of certain crops (p. 351). The more general farm crops, notably corn and timothy in regular rotation, are then grown to advantage until the peat has changed from the brown, fibrous material to the black, well disintegrated variety. For hay, timothy is often seeded with alsike clover, giving frequently from 1½ tons to 2½ tons per acre. Celery is probably the most important crop. An acre of celery will produce from 900 to 1,000 dozen of bunching plants. Onions constitute another favorite, yielding an average of about 500 bushels per acre. A production of 50 to 70 bushels of oats per acre is not unusual. Buckwheat matures early and besides being profitable aids in shading more susceptible crops. The yield in potatoes is heavy, ranging from 100 to 300 bushels per acre, but the quality of the tubers is not as good as those in sandy soils. Rice and corn grow well and frequently without the use of lime. Peat soils form blue grass land and thus furnish the best of pasturage. They can be turned with profit into corn land yielding about 40 to 50 bushels per acre. Rotations should include such crops as prefer a soil inclined to "acidity" (p. 372), or such plants as are indifferent to it. The statement is often made that heath plants and others growing upon peat require an acid soil. It has been shown elsewhere in this chapter that humic acids in peat are complex and unstable compounds, as yet but very little understood. They have a relatively short-lived existence in the soil, and recent investigations have clearly set forth the logical fallacy involved in much of the prevalent interpretation of soil acidity.[1] The matter requires much further work before any information can be accepted as conclusive (Chapter IX, pp. 334, 342).

There are many wood lots, country homes and parks which include small peaty depressions and sphagnum bogs. With little trouble these could be maintained as bog gardens for orchids, wild rosemary, fringed gentian, sundew, pitcher plant, lobelias and others.[2] Where a bog garden can be made either at the side of a pond, along a running stream, or in a wet meadow, it is well worth trying to attempt it along lines which resemble the natural vegetation units (Chapter VI). Some species can be purchased from nurserymen, but the native bog plants will soon disappear completely as the bogs are drained for farm lands or filled in to make building lots.

The Chemical Nature of Peat Soils in Relation to Bog Vegetation.—The ecological relation of plants to soils, particularly to the chemical nature of the substratum, is especially interesting and has been extensively studied from the standpoint of the distribution of species, the succession of vegetation, and the adaptability of crops to certain soils. In mountainous countries, and even in states like Ohio, with soils of morainal and of varied geognostic nature, one can observe sharply delimited distinctions in the distribution and in the whole appearance of vegetation units. And yet, though many species are confined to soils with a definite chemical relationship, wheat,[3] corn,[4] sugar beet,[5] and others, and the larger forest types of the United States are not related to soil types; nor is their range of distribution limited or affected by them. Many plants can grow on soils widely dissimilar in kind; even the finer distinctions between soil types are of little value in understanding the range of such species. Are the reasons for the generally observed distinctions to be sought in the chemical constitution of the soil, or is the distributional relationship due to the physical characters, particularly to relations prevailing in regard to the amount of available water and the specific quantity required by the plants, and to the thermal and sanitary conditions in the soil?

Not all field work is adapted to throw light on this vexed question

[1]Cameron, F. K., The soil solution. Easton, Pa., 1911, p. 55 and l. c. p. 372.

[2]Manning, H. W., Two kinds of bog garden. Country Life in America, Vol. XIV, 1908, pp. 379-380.

Miller, W., What England can teach us about gardens. New York, 1911.

[3]LeClerc, J. A., Tri-local experiments on the influence of environment on the composition of wheat. U. S. Dept. of Agr., Bureau of Chemistry, Bull. 128, 1910.

[4]Smith, J. W., Relation of precipitation to yield of corn. Yearbook U. S. Dept. of Agr., 1903, pp. 216-224.

Straughn, M. N., and Church, C. G., The influence of environment on composition of sweet corn. 1905-1908. U. S. Dept. of Agr., Bureau of Chemistry, Bull. 127, 1909.

[5]Wiley, H. W., Influence of environment on the composition of the sugar beet, 1901-1904. U. S. Dept. Agr., Bureau of Chemistry, Bull. 96, 1905.

of a long standing dispute. Difficult as is the attempt to establish a correlation between vegetation and any one factor of the environment, it is possible, however, to make such a correlation with peat soils, within the area here investigated.

It is now generally recognized that the nature of a lake and bog environment is constantly selective, and that the associations and societies of plants succeeding one another are each characterized by a definite physiognomy in response to their dependence upon soil conditions under atmospheric influences essentially similar otherwise. In an earlier chapter the writer has listed the successions of the more genetically related vegetation units, their associations and societies, occurring in Ohio lakes and peat deposits.

The several analyses submitted in this chapter do not reveal the obvious distinctions between successions of vegetation on peat soils and the changes in the chemical character of the peat. The fact that certain plant associations have an absolutely defined morphological and topographic distinction, and the fact that these contrasts must be attributed to conditions prevailing in the soil, direct special attention to the contrasts between peat soils of the various vegetation units or groups of plants. The following series in table 33 is especially suggestive in showing the more typical features of the correlation.

TABLE 33

CORRELATION BETWEEN VEGETATION UNITS IN OHIO BOGS AND CHARACTER OF PEAT SOILS

Vegetation unit, locality and number of sample	Moisture in air-dried sample.	Volatile matter	Fixed carbon	Ash	Nitrogen	Potash, K_2O	Phosphoric acid, P_2O_5	Sulphur	Calorific value: calories
Bog meadow succession. Cranberry-sphagnum association.									
Lakeville, No. 73	7.14	67.42	24.91	7.67	2.39	-----	-----	0.28	5039
Lakeville, Holmes, No. 72	6.96	69.15	25.04	5.81	2.38	-----	-----	0.23	5317
Buckeye Lake, No. 41	9.23	67.99	24.46	8.45	1.01	0.12	0.03	0.43	4792
Bog shrub succession. Alder-maple association.									
Buckeye Lake, No. 40	7.87	74.79	21.35	3.86	2.52	0.12	0.03	0.28	4632
Orwell, No. 44	9.08	63.24	26.18	10.58	2.45	-----	-----	0.46	4981
Geauga, No. 49	9.01	57.05	23.51	25.44	2.13	-----	-----	0.77	4169
Bog forest succession. Tamarack association.									
Canton, No. 76	8.01	62.03	31.84	6.35	3.39	-----	-----	0.33	4912
Leman's Bog, No. 82	8.58	62.44	25.44	12.32	2.58	-----	-----	0.52	4678
Fox Lake, No. 78	8.99	54.46	25.02	20.52	2.41	0.15	0.28	0.89	4375
Eckert Bog, No. 56	9.36	60.73	29.62	3.65	1.66	-----	-----	0.21	5409
Copley Bog, No. 58	10.54	60.66	28.92	10.42	2.88	-----	-----	0.75	4835
Mesophytic forest succession. Maple-ash-elm association.									
Mantua Bog, No. 47	10.40	56.33	26.16	17.51	2.46	0.19	0.42	0.86	4550
Bradley Pond, No. 51	10.11	60.09	27.96	11.95	2.24	0.27	0.19	0.29	4856
Brimfield Bog, No. 52	11.25	57.64	31.19	11.17	2.33	-----	-----	0.74	4758
Copley Bog, No. 59	11.35	56.85	31.87	11.28	2.72	-----	-----	0.89	4923

The correlation phenomena between vegetation units in bogs, and the character ot the peat soil, are not in all cases as those given in table 33. There are many exceptions to the rule, for reasons which cannot, at present, be stated clearly without further study. On the whole, however, the results may be summarized in the following well-defined relations:

1. In color, Ohio peat ranges from a greenish and grayish brown, due to the presence of clay and marl, through various shades of brown to an almost black variety. The colors are darker when the peat is wet. In general, the light-colored peat supports a meadow-like vegetation; trees and shrubs are found growing on dark-colored peat. In texture, peat varies from a loosely compacted, fibrous, heterogeneous meshwork of plant débris to the fiberless, homogeneous variety. Here also, a close relationship exists between vegetation cover and soil conditions. Coarsely fibered peat is derived from, and generally supports, grass-like and sedge-like plants. It is usually poorly decomposed, except in localities where weathering and biochemical processes reduce the organic débris to simpler, dark-colored substances. Mature vegetation types, such as thickets and forests, grow upon darker and much more thoroughly decomposed peat and the débris is likely to be more woody.

The water plants form a soft, oozy, structureless peat. It only occurs as the bottom layer of peat-depositing lakes and ponds.

2. The physical water content of peat is higher in the coarser, fibrous substratum of the bog meadow association, but the amount of moisture retained when air-dried, is lower (table 33). The mat, when adjoining open water, adjusts itself easily to changes in the water level of the basin. With the disintegration of the plant tissues and the advance of maturer vegetation types the water-holding capacity of peat increases. The concentration of the bog water solutions is very low, varying between 40 and 260 parts per million of total solids (table 29-30). The osmotic pressure and the acidity of the solutions differ but slightly between the various grades of peat soil and their respective vegetation cover.

3. Reducing processes in peat soils, judged by methylene blue or a one per cent. starch-iodide solution, increase from any marginal point of a peat-depositing lake to the bog meadow association and decrease as the deciduous forest association is approached.

4. The nature of the changes which have taken place in the transformation of vegetable dèbris into peat is only partly understood. The principal changes are a relative loss in oxygen and hydrogen, and a progressive increase in carbon and nitrogen. This is clearly shown (tables 24 and 33), in passing from the fibrous peat substratum of bog meadows to the structureless peat occupied by bog forests and deciduous trees.

5. In poorly decomposed peat such as that of the bog-meadow variety, the percentage of volatile combustible material is high, the percentage of fixed carbon, nitrogen and ash is low. In well decomposed peat and in that of the advanced forest association, the reverse is true (table 33).

6. The higher ash content in peat from bog shrub and bog forest associations is believed to be due largely to wind-blown silt; a bog meadow association interferes less with wind work than the timbered area of a deposit.[1] But the chief source of a high ash content is flooding from streams and rain wash from hillsides.

7. Peat contains potash and phosphoric acid in comparatively inconsiderable quantities—only a fraction of one per cent.—whereas the percentage of calcium and nitrogen is very high, varying from one to almost four per cent. (tables 31 and 32). The capabilities of a soil for crop production are usually judged from the study of its chemical character, and soils markedly deficient in phosphates, potash and other salts are looked upon as barren and sterile; maintenance of fertility is connected with abundance of these constituents, and their effect on plants rather than on the soil. In peat soils from the bog meadow to that from bog-forests, the essential mineral salts of the agricultural tripod, it seems, play minor roles in protoplasmic activities and in growth and ripening of bog plants.

8. More systematic investigations from the standpoint of agricultural chemistry have shown that in the several bog associations the number of possible inorganic nitrogenous substances, the quantity of nitrites, nitrates and ammonia is quite small, ranging from a few thousandths to a few hundredths parts per million (tables 29 and 30). Practically all the nitrogen contained in peat is, therefore, of organic nature.

9. Only a small amount of nitrogenous substances can be extracted from peat by means of water from any of the bog associations under consideration. The relatively low amount of free ammonia and the large amount of oxygen consumed indicate that the organic matter in any one of the related vegetation units is not in an advanced stage of decomposition.

10. The solubility of coarsely fibrous peat from the bog meadow is less than that of peat in a finer state of division and supporting a more advanced stage of bog successions. This condition seems to point to the fact that the organic compounds arise mainly through the action of microörganisms (tables 20 to 22). Compounds associated with the decomposition products of proteins by mineral acids are here practically out of the question.

11. Little is known as to the chemical constitution of peat in passing from the fibrous, bog meadow variety to the structureless

[1] Beyer, S. W., Peat deposits in Iowa. Iowa Geological Survey, Vol. XIX, 1908, p. 69 8.

material occupied by trees. No data are at hand concerning the transition products of proteins and carbohydrates arising in the vegetable débris during its transformation into peat. Biochemical technique has not permitted, as yet, the analysis or the preparation of isolated peat soil constituents of comparative purity. They are undoubtedly of access for chemical investigation and isolation. Known methods of investigation in biochemistry have been applied in the study of decomposition products of organic compounds in mineral soils.

Schreiner and Schorey, Jodidi, and Robinson have more recently isolated and identified a number of these compounds. In peat soils the compounds are present in small amounts, the number of transition products is undoubtedly larger, and their effects upon living plants are for the most part unknown. It is difficult to understand how a substance present in peat soils or in bog water in such minute concentration that for ordinary chemical analysis its influence is negligible, may nevertheless exert a profound effect upon the growth of plants (tables 10 to 19). It seems necessary to assume that this distinctly disproportionate effect is produced by external action, by biochemical metabolic products. Peat is a heterogeneous sytem of substances and its variable composition renders it difficult to determine what substances are injurious and what compounds can actually be absorbed and assimilated by plants. The presence of one substance or the concentration of another constituent, as determined by quantitative analysis, may have only an apparent relation, and not necessarily a causal value. This might be because the substances are differently distributed on account of differences in solubility or oxidation, are absent in one phase of the decomposition process because of differences in the bacterial flora at work in different layers, or vary greatly with reference to the diosmotic properties of the absorbing organs of plants. Humus has long been recognized as a very important factor in soil fertility, and yet almost all the difficulties in any special problem with humus or peat arise in the lack of knowledge of the chemical nature, and the effects on plant life of the various organic compounds resulting from weathering processes and from the activity of microörganisms. The complexity of the problem emphasizes the need of physiological studies. Bacteriological-chemical and physiological analyses deserve on that account a closer consideration. The determination of these compounds by chemical means alone will be valuable only in part for investigations in ecology.

Numerous problems of experimentation have arisen quite apart from the main question itself.

It would be interesting to determine the water requirement of bog plants for a growing period and to compile the results on a basis of the water needed for one part of ash yielded. Data on the specific differences in the ratio, i. e., on the water requirements of bog plants and the percentage of ash in herbs, shrubs and trees covering peaty basins, are not at hand. The analyses reported by Sargent in the Ninth Census of the forest trees of North America give the percentages of ash for some of the trees common to bogs. *Pinus strobus* 0.19; *Liriodendron tulipifera* 0.23; *Magnolia acuminata* 0.29; *Betula lutea* 0.31; *Larix laricina* 0.33; *Thuja occidentalis* 0.37; *Acer rubrum* 0.37; *Quercus alba* 0.41; *Fraxinus americana* 0.42; *Tsuga canadensis* 0.46; *Nyssa sylvatica* 0.52; *Fraxinus nigra* 0.72; *Ulmus americana* 0.80; *Quercus palustris* 0.81; *Ulmus fulva* 0.83; *Carya cordiformis* 0.90; *Celtis occidentalis* 1.09. The data are interesting in showing that the majority of trees frequenting bogs have a percentage of ash less than 0.5, and only a few of the deciduous species occurring on Ohio peat deposits have a percentage of ash as high as 1.5. Comparisons of the quantities of mineral salts contained in peat deposits, differing so widely in ash constituents from land soils, again point to the fact that differences in mineral components are trifling as compared with the biological processes in the substratum and the differences in the available water.

A closer study of the chemical analysis of Ohio peat will show that the opinion expressed by the supporters of the chemical theory is of limited application. It has been shown that acidity, toxicity, and reducing action of peat soils are merely stages in the decomposition of the organic matter, and that an efficient natural process exists for the maintenance of productivity relations. In the natural successions which ensue, each plant association augments the efficiency of the soil as a habitat. Nature does not know soil exhaustion. Several types of plant associations and particularly forests of varied physiognomy, growth-form and function are associated together in groups upon a habitat similar in chemical constituents. Not only the distributional relationship of natural vegetation successions, but experimental work as well, show that differences in the mineral components of peat soils are trifling compared with the biological processes in the substratum and the differences in available water. It cannot be too strongly emphasized that the prime condition determining the deciduous forest association is not an increase in the mineral constituents in the soil. As Cameron[1] has pointed out, the plant food theory of soils must pass with the recognition of the general failure of the older methods of soil analysis to bring out the dynamic nature of soil processes. Diseased (organically poisoned) soils must be treated by such means as increase its oxidizing power and its absorptive properties. The fertilizers generally used are, undoubtedly, effective in this way, but better physical soil conditions, especially in sanitation and water supply, are the more efficient factors. It is not difficult to see on what basis of knowledge we should advance in order to improve abandoned farms, to increase the productivity and to maintain the fertility of

[1]Cameron, F. K., The soil solution. Easton, Pa. 1911, p. 16.

soils other than peat. Recent investigations (p. 386), have shown that cereals and other agricultural plants of the same variety obtained from different soils possessing widely different chemical and physical characteristics, when grown side by side in one locality, yield crops which are almost the same both in appearance and in chemical composition. The chemical composition of mineral soils and seed[1] play a relatively small part in influencing the composition of crops. The differences in yield are mainly due to climatic conditions, such as temperature and precipitation, at the time of the period of maximum growth. The results on the leaching of organic and inorganic substances from wheat seeds and others, and from mature plants especially at the ripening stage, and the accumulation of decomposition products of organic substances in the soil, have shown the necessity of a fuller understanding of the biochemistry of the organic matter of soils, and of the biological changes taking place therein. Better cultural methods, better seed, and fuller knowledge of soil processes will alone control the dangers of soil deterioration and accelerate the increase of yield.

[1]Harris, J. A., on the significance of variety tests. Science, N. S., Vol. 36, 1912, pp. 318-320.

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